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THE PARAGENESIS OF CERTAIN SULPHIDE INTERGROWTHS.

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INTRODUCTION.

During the past decade the application of the metallographic microscope to the study of ores has greatly extended the knowledge of the structure of opaque minerals. Relations hitherto unsuspected between sulphides and between other metallic minerals have been discovered, and the paragenesis of ore minerals inferred from these relations has in the deduction of ore genesis become of considerable importance. In interpreting observations it has been found advisable, especially in the study of enriched copper deposits, to establish criteria of structure both for replacement and for contemporaneity of minerals. Replacement relations have been said to be exhibited by many types of mineral intergrowth. Contemporaneity of component minerals has been asserted in graphic sulphide intergrowths resembling in structure that of eutectic metallic alloys. While the relations in many replacement structures of metallic minerals are clearly proven, the interpretations of paragenesis in certain intergrowths of this type and in all of the graphic sulphide intergrowths so far described have been contradictory.

Laney[1] discovered intergrowths of bornite and chalcocite in the

[1] Laney, F. B., *Proc. of U. S. Nat. Museum*, Vol. 40, p. 520. ECONOMIC GEOLOGY, Vol. 6, p. 399.

Virgilina District, North Carolina, which he stated to be a eutectic of the two minerals and to indicate their contemporaneous deposition. Gilbert and Pogue[2] describe similar relations of bornite and chalcocite in the ore deposits of the North Mt. Lyell Mine, Tasmania, and conclude simultaneous deposition of the sulphides. Graton and Murdoch[3] come to the same conclusion regarding intergrowths of bornite and chalcocite at Butte. Ray[4] believes graphic intergrowths of bornite and chalcocite in the covellite zone at Butte to be due to the reaction of iron in solution upon colloidal chalcocite influenced by the presence of pyrite and thus suggests simultaneous origin of the two copper sulphides. Rogers[5] regards an irregular intergrowth of bornite and chalcocite from Butte as due to replacement and suggests that the "eutectic" structure of Laney may be similarly caused, but he offers no illustrations of such structure and advances no proof of such a conclusion. Lastly Segall[6] presents an examination of bornite-chalcocite ore from the Peavine District, Nevada, showing the characteristic graphic intergrowth. While his conclusion is merely tentative, he points out similarity between this structure and others due to replacement.

Intergrowths of sulphides due to replacement along crystallographic or cleavage planes have also been variously interpreted. Ray[7] describes a triangularly reticulate structure in Butte chalcocite due to minute specks of bornite and covellite. He believes this to be due to a purifying influence exerted during the crystallization of chalcocite. Segall[8] has found a similar pattern developed in bornite by veinlets of chalcocite and has asserted it to be due to replacement of chalcocite by bornite. Graton and Murdoch[9] illustrate structures of identical appearance to those of Ray

[2] Gilbert, C. C., and Pogue, G. E., *Proc. of U. S. Nat. Museum,* Vol. 45, pp. 609–625.

[3] Graton, L. C., and Murdoch, J., *Trans. Am. Inst. Min. Eng.,* Vol. 45, p. 768.

[4] Ray, J. C., Economic Geology, Vol. 9, No. 5, p. 479.

[5] Rogers, A. F., *Mining and Scientific Press,* October 31, 1914, p. 686.

[6] Segall, J., Economic Geology, Vol. 10, No. 5, p. 469.

[7] Ray, J. C., *loc. cit.,* p. 479.

[8] Segall, J., *loc. cit.,* pp. 465–466.

[9] Graton, L. C., and Murdoch, J., *loc. cit.,* pp. 759 and 784, Figs. 18 and 34.

and Segall. Replacement of bornite by chalcopyrite and chalcocite is stated to be their origin. It would seem that such similar structures might be due to similar causes.

Examples of the so-called "eutectic" or graphic intergrowths and of intergrowths following cleavage or crystallographic directions have been observed by the writer in examinations of sulphide ores from Tintic, Utah, and several eastern copper deposits. A physical-chemical consideration of the former class, comparison with polished surfaces of true eutectic alloys, and the discovery of replacement relations between the sulphides themselves unite to form convincing proof of the metasomatic origin of this type of intergrowth. Various new data of interest with reference to the latter class have also been found. It is with the hope that the obscurity of conflicting opinion regarding these intergrowths may be somewhat enlightened that this paper is presented.

THE PHYSICAL CHEMISTRY OF GRAPHIC INTERGROWTHS.

It is of importance both regarding the nomenclature and the genesis of graphic intergrowths of sulphide to know (1) if they can be eutectics and (2) if not being eutectics they can be due to contemporaneous deposition of two sulphides.

It is, of course, true that in a melt of two sulphides a eutectic mixture might result upon solidification. The structure result-

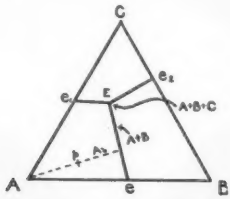


FIG. 1. Ideal equilibrium diagram of a three-component eutectic system.

ing under such conditions would be similar to that of a eutectic metallic alloy (Fig. 1, Pl. I). However, in the case of the deposition of the ores in which sulphide intergrowths have been found,

EXPLANATION TO PLATE I.

FIG. 1. (× 650.) Alloy of 70 per cent. silver, 30 per cent. copper. Showing excess of silver and eutectic. Light = Ag; dark = Cu.

FIG. 2. (× 100.) Graphic intergrowth of bornite and chalcocite from Bristol, Conn. Bornite predominant. Bornite = dark; chalcocite = light; gangue = black.

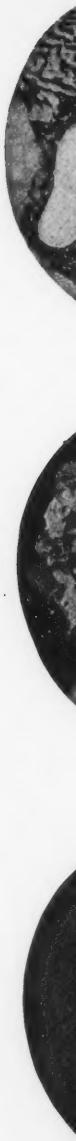
FIG. 3. (× 100.) Graphic intergrowth of bornite and chalcocite from Bristol, Conn. Chalcocite predominant.

FIG. 4. (× 100.) Graphic intergrowth of bornite and chalcocite from Bristol, Conn. Bornite and chalcocite in approximately equal amounts.

FIG. 5. (× 360.) Transitional contact between bornite and chalcocite, Bristol, Conn.

FIG. 6. (× 1,000.) Veinlets of chalcocite in bornite, Bristol, Conn.

PLATE I.



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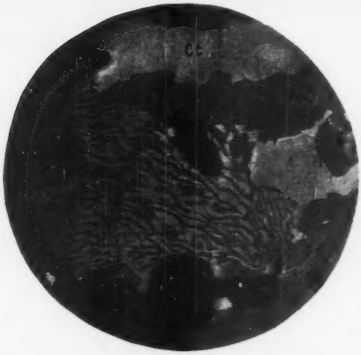

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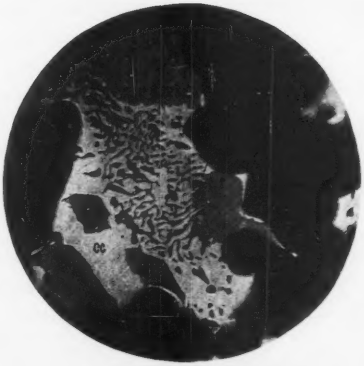

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pure melts have certainly not been concerned; and deposition has undoubtedly occurred from solution. If it be assumed that water alone has been the solvent of two sulphides, it must be considered as a component of the system. In such a highly hypothetical system if a composition *p* (Fig. 1) be assumed, a binary intergrowth might result with lowering temperature along the line *eE* and eventually the ternary eutectic of *A, B,* and *C* would form. Most certainly no such final product is to be found in ore deposits.

It is evident that the consideration of sulphide deposition in such a simple system is quite impossible, and as a matter of fact it is well known that other substances must be present and enter into the reactions which result in the precipitation of sulphides. Saline constituents and probably dissolved gases are concerned in the process. The systems are complex and moreover doubtless change from point to point not only in concentration but in composition. Though the variable nature of the components of the systems and the lack of knowledge concerning the concentrations and thermal conditions under which the components react prevent the representation of conditions of sulphide deposition in equilibrium diagrams, the indefinite state itself of the subject compels the admission of the possibility of simultaneous deposition of sulphides in intergrowths. As it seems hardly probable, however, that the solutions under consideration are at all eutectiferous, it is extremely hazardous to apply the term "eutectic" to sulphide intergrowths.

In a complex system, such as solutions depositing sulphides might be regarded, it is probable that an order of deposition similar to that of simpler systems prevails. In Fig. 1, Pl. I, the excess of silver above the eutectic composition is deposited in massive areas and the eutectic of silver and copper in the interstices of these areas. Similarly a graphic intergrowth of contemporaneously deposited sulphides would be expected to be accompanied by an excess of one constituent only. It may be seen from Figs. 2, 4, 5, 9 and 10 that almost invariably graphic intergrowths of sulphides are flanked by massive areas of both constitutnets. While this criterion, in the present indefinite state of knowledge

of these complex systems, is by no means conclusive, it is suggestive, in spite of the theoretical possibility of primary sulphide intergrowths, of origin other than by contemporaneous deposition of the sulphides.

THE STRUCTURE OF GRAPHIC INTERGROWTHS.

While the conclusions drawn from the consideration of sulphide intergrowths in the light of the theory of chemistry are open to great doubt, polished surfaces of specimens show relations of but one interpretation. Under lower powers of magnification it is true the genesis of the structure is obscure and former assertions regarding contemporaneous origin of the sulphides of the intergrowths can be well understood. Under high magnification the sulphides, however, appear in undoubted metasomatic relation.

Ore from Bristol, Connecticut, consists of veinlets of bornite and chalcocite in intimate mixture and contained in a quartz gangue. Chalcocite in vugs in many places coats bornite and is certainly later in origin than the bornite. The ore of the veinlets, however, also shows mingling of the two sulphides in massive areas and in graphic intergrowths and might well be believed in cursory examination to be formed of contemporaneously deposited sulphides.

These intergrowths are all quite typical. They are composed of twisting tongues of the sulphides with sharp smooth contact. The embayments and tongues turn sharply to form hooks and often join together to make an intricate network. The characteristic intergrowth contains the curved, elongate bodies of bornite and chalcocite in approximately equal width, but they often widen or narrow and many terminate in sharp, sword-like points. The intergrowths are generally notable for a graceful irregularity and an entire lack of any significant orientation of their component bodies.

A careful study of polished surfaces of the graphic intergrowths, even under low magnification, reveals evidence of replacement. In Fig. 2, which illustrates an intergrowth with bor-

nite predominant, the characteristic structure appears. At the magnification (100 ×) little difference between this structure and that of a true metallic eutectic (Fig. 1) can be detected. The veinlets in places, however, seem to be more lenticular in the sulphide mixture and are more acutely ended. The contacts between the bornite and the intergrowth are also not smooth as between the silver and the eutectic, but veinlets of chalcocite penetrate the solid bornite and give a serrated contact. As chalcocite increases in amount in the intergrowth (Fig. 4) such contacts become more noticeable. In the center of the photograph long veinlets of chalcocite run into the mass of bornite to the right. At the top stringers of chalcocite finger through solid bornite. In this photograph are also to be seen (at bottom) small rounded areas of bornite in solid chalcocite and in many places veinlets of chalcocite following contacts or cutting across massive bornite. When chalcocite becomes predominant (Fig. 3) the intergrowth loses much of its resemblance to the eutectic structure. It is believed that Fig. 2 represents an early stage of replacement of bornite by chalcocite, Fig. 4 a more advanced stage and Fig. 3 a stage when the process, though nearly complete, has left irregular residual masses of bornite.

That intergrowths result in intermediate stages between pure bornite and its complete replacement by chalcocite is indicated in places at the contacts of the sulphides. Solid chalcocite (Fig. 5) containing a few rounded specks of bornite changes to the characteristic intergrowth which in turn gives way to solid bornite. Chalcocite veinlets penetrating bornite appear here also.

Under low powers the evidence of replacement while suggestive is not conclusive; but with greater magnification doubt both regarding replacement and the succession of sulphides is resolved. Veinlets of chalcocite (Fig. 6) appear in areas of bornite which seem homogeneous at low magnification. Chalcocite characteristically follows the contacts of bornite and gangue. The veinlets when narrow have a dark center line (Fig. 6) which, as they widen and replacement advances, disappears. The bornite of the intergrowth illustrated in Fig. 2 under high magnification is seen

EXPLANATION TO PLATE II.

FIG. 7. (× 1,000.) Veinlets of chalcocite in a graphic intergrowth of bornite and chalcocite from Bristol, Conn.

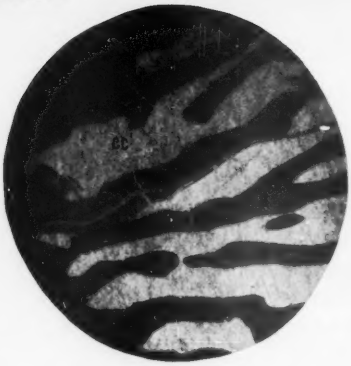
FIG. 8. (× 2,100.) Embayments of chalcocite in a graphic intergrowth of bornite and chalcocite connected by veinlets, Bristol, Conn.

FIG. 9. (× 650.) Beginning of graphic intergrowth between pearcite and galena. Gemini Mine, Tintic, Utah. (Galena, light; pearcite, dark; gangue, black.)

FIG. 10. (× 246.) Graphic intergrowth in which pearcite follows in places cleavage of gelena. Gemini Mine, Tintic, Utah. (Galena, light; pearcite, dark; gangue, black.)

FIG. 11. (× 3,040.) Graphic intergrowth of galena and covellite, Gemini Mine, Tintic, Utah. (Covellite, dark; galena, light.)

FIG. 12. (× 1,670.) Reticulate intergrowth of chalcocite and bornite, Bristol, Conn. (Bornite, dark; chalcocite, light.)



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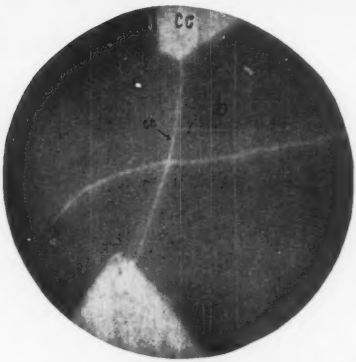

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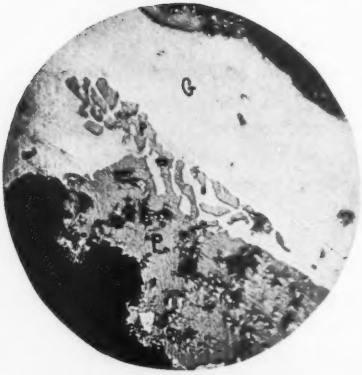

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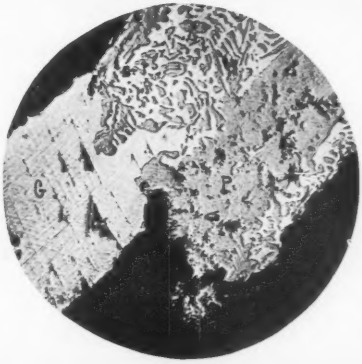

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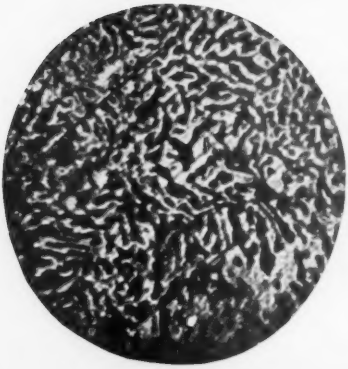

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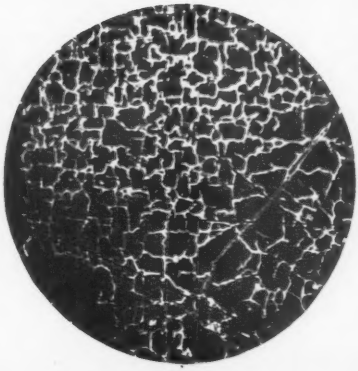

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(Fig. 7) to be traversed by many very minute veinlets of chalcocite. With extremely high powers embayments of the chalcocite of the intergrowths are seen to be connected (Fig. 8) by veinlets ordinarily invisible.

The inference from the above illustrations that the chalcocite of the main period of deposition has been invaded by later veinlets of chalcocite must be considered. Etching of the polished surfaces proves that no cross-cutting relations exist between massive chalcocite and the sulphide of the veinlets, that, as Laney[10] asserts, the crystalline structure of adjoining chalcocite embayments separated by bornite is often continuous, and that veinlets between such embayments are entirely continuous with the larger areas of chalcocite.

From these relations it seems certain that the chalcocite replaces bornite, that the replacement proceeds along minute, interlacing veinlets, and that the graphic intergrowth, a stage where these veinlets are broadened in places and the bornite masses are rounded where veinlets cross, is due to metasomatism.

Beautiful examples of graphic intergrowths between pearcite ($Ag_9(Cu)AsS_6$) and galena are to be observed in the ore from the nineteenth level of the Gemini Mine, Tintic, Utah. Here the mixture traverses a gangue of quartz in veinlets which follow fracture lines in the gangue.[11] The intergrowths appear as transitions between pearcite and galena (Fig. 9) and contain veinlets of pearcite fingering into the galena and branching forms which seem without doubt to follow the cleavage of the galena (center Fig. 10). Replacement of galena by pearcite is here strongly indicated.

A metasomatic structure similar to graphic intergrowth has also been found in the silver ores of Chañarcillo, Chile. Fans of native silver replacing cerargyrite show under high magnification residual horn-silver and have the appearance of the graphic structure.

The most convincing case of metasomatic graphic intergrowth is to be found in the ore of the fifteenth level of the Gemini Mine,

[10] *Loc. cit.*, p. 520, Pl. 69, Fig. 1.

[11] Lindgren, W., Economic Geology, Vol. 10, No. 3, p. 239.

Tintic, Utah. Galena in a quartz gangue is accompanied by covellite. The covellite coats galena masses and is undoubtedly of later deposition. The covellite, however, also forms with the galena a typical graphic intergrowth (Fig. 11). The characteristic hooks and tongues of covellite are present and the intergrowth is entirely similar in structure to those of bornite and chalcocite. In view of the replacement relations between the two sulphides elsewhere,[12] this intergrowth must be considered to be of relative secondary origin.

RETICULATE INTERGROWTHS.

The triangularly reticulate intergrowths illustrated by Graton and Murdoch,[13] Ray[14] and Segall[15] have been variously interpreted by these authors. Graton and Murdoch find chalcopyrite replacing bornite in a triangular pattern which corresponds with the etch pattern of the latter mineral and follows an undoubted crystallographic, possibly a cleavage, direction of bornite. A similar reticulate structure due to specks of bornite in massive chalcocite is observed. It is attributed to the crystallographic structure preserved by residual bornite in an advanced stage of replacement by chalcocite. The same structure described by Ray is said to be due to the purifying along certain directions of chalcocite during its crystallization. It is probable that the interpretation by Graton and Murdoch is correct and that this structure is one of replacement.

Segall believes the triangular structure developed by narrow veinlets of chalcocite in bornite to be originated by the replacement of chalcocite by bornite and the structure to be due to the crystallographic or cleavage directions of chalcocite. The three directions of etching, which represent crystallographic or cleavage lines, in orthorhombic chalcocite, however, are at right angles. The etch form is rectangularly reticulate. The triangular form of etching occurs on isometric crystals of chalcocite; but chalco-

[12] *Loc. cit.*, pp. 237–239.
[13] *Loc. cit.*
[14] *Loc. cit.*
[15] *Loc. cit.*

cite of this system has not yet been certainly found in nature. On the other hand, bornite usually gives a triangular etch figure and undoubted replacement in bornite gives often a triangularly reticulate structure. It would, therefore, appear, in spite of the presentation by Segall of rather unconvincing evidence of bornite veinlets in chalcocite, that the bornite is replaced by chalcocite.

Polished surfaces showing triangularly reticulate intergrowths examined by the author from Tariffville, Connecticut, indicate that in the replacement of bornite the structure may in the first stage be formed by narrow veinlets of chalcopyrite or chalcocite. As replacement advances the veinlets widen but remain purest at the center. The final stage of replacement by chalcocite is illustrated by Graton and Murdoch and by Ray.

This type of structure is characteristic of metasomatism where the replacing mineral follows crystallographic directions of the replaced. The existence of a second class where the replacing mineral follows its own crystallographic directions and forms skeletal crystals has been suggested by the study of an intergrowth from Bristol, Connecticut.

A coarsely crystalline mass of chalcocite in the Bristol ore surrounds a core of bornite against which it lies with contacts perfectly smooth at low magnification. At extremely high powers (Fig. 12) the chalcocite is seen fingering into the bornite in a rectangularly reticulate structure. This incipient stage of replacement where carried to completion forms, as proved by etching, continuous crystals of chalcocite. It is, therefore, believed that in the minute veinlets, whose direction corresponds roughly to the crystallographic structure of chalcocite, the chalcocite is of parallel orientation and that the reticulate intergrowth is here essentially a crystal skeleton.

CONCLUSION.

Triangularly reticulate structures of bornite with chalcopyrite and chalcocite are due to replacement of the bornite along crystallographic directions by the latter sulphides. Such intergrowths typify a class in which the structure of the intergrowth is deter-

mined by the crystallographic directions of the mineral replaced. The existence of a second class in which the structure is in accord with the form of the replacing mineral is indicated by a rectangularly reticulated replacement of bornite by chalcocite.

Graphic intergrowths of bornite and chalcocite present undoubted evidence of the replacement of the former by the latter. The relations of the components in similar intergrowths of pearcite and galena and of covellite and galena indicate strongly a metasomatic origin. Little doubt can exist that such graphic intergrowths of sulphides are usually due to replacement.

In a consideration of the genesis of the ores in which these intergrowths are contained, the origin of the solutions depositing the metasomatic minerals is of the utmost importance. The reticulate intergrowths of the Connecticut copper deposits occur in association with veinlets of oxidized minerals, and it is believed they are due to the action of descending solutions. The similar intergrowths of Butte may well be also caused by such downward enrichment.

The graphic intergrowths of bornite and chalcocite of Bristol, Connecticut, bear chalcocite as far as observed of the orthorhombic form. Chalcocite in this deposit often shows orthorhombic crystalline forms. Allen[16] states that chalcocite deposited at a temperature above 91° C. is isometric. It would, therefore, appear that the chalcocite of Bristol was deposited at a temperature lower than 91° C. The structure of the veins and their association with igneous rocks indicate an origin genetically connected with the last effusion of Triassic trap and comparatively near the surface. The temperature of such genesis would probably be somewhat above 100° C. but less than 250° C. It is evident that so far as the genetic temperatures may be accepted the chalcocite is later than the primary mineralization. Further evidences that the chalcocite was deposited from cool or cold waters is to be observed in the structure of the microscopic chalcocite veinlets which resemble in every way those due to enrichment by descending solutions. It is, therefore, believed that the chalcocite developed

[16] E. Posnjak, Allen, E. T., and H. E. Merwin, Economic Geology, Vol. 10, No. 6, p. 491.

from the action of cold solutions upon the primary ore and is possibly due to downward sulphide enrichment.

The graphic intergrowths of pearcite and galena from Tintic, Utah, occur in a secondary ore.[17] The galena is believed to be due to deposition from descending solutions and the pearcite which replaces it is undoubtedly of similar origin. The intergrowth of covellite and galena from Tintic is certainly formed by the precipitation of covellite from downward moving, partly oxidized solutions.[18]

Sulphide intergrowths, both graphic and reticulate, are, as far as observed by the author, of secondary origin. The metasomatic processes by which they were formed seem in many cases to have acted considerably later than the period of primary ore deposition. Such structures it would therefore seem may often result during downward secondary enrichment.

[17] Lindgren, W., ECONOMIC GEOLOGY, Vol. 10, No. 3, p. 239.
[18] Lindgren, W., *loc. cit.*

NOMOGRAPHIC SOLUTIONS OF CERTAIN STRATIGRAPHIC MEASUREMENTS.

HAROLD S. PALMER.

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INTRODUCTION.

This paper is offered with the hope of giving a quick and easy method for calculating from topographic and geologic measurements the thicknesses of strata, with a degree of accuracy sufficient for most geologic purposes. The principles underlying the proposed methods are rather complicated, but it is hoped that the explanatory diagrams will make the method virtually "fool-proof." A knowledge of trigonometry is not necessary; merely the ability to follow simple directions and to interpolate values on a logarithmic scale similar to that of a slide rule.

The writer wishes to acknowledge the very kind help which Mr. Herbert L. Seward, of the Mechanical Engineering department of the Sheffield Scientific School, gave in developing the nomograph.

PURPOSE.

Columnar Sections.

Where the geologist is so fortunate as to find the strata, whose thickness he wishes to measure, cut at a very steep angle to the bedding plane, it is a very simple operation to get the desired data by direct measurement. It often happens, however, that the surface of the ground over which the geologist must pass in measuring his section, is at a low angle to the bedding, and then direct measurement is difficult. Further troubles are caused by gaps in the outcrop, as is often the case where shales are interbedded with more resistant rocks. In this case it is impossible to measure bed by bed, and the geologist must calculate the thickness repre-

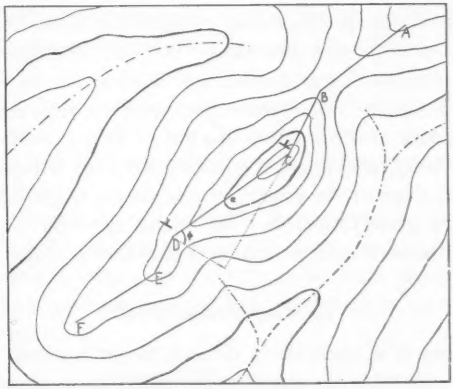


FIG. 2.

sented by the gap from measurements of the direction and length of the traverse across them, and the dip and strike of the beds. This must also be done in the case of massively bedded rocks; in all cases, in fact, where the bedding is not clearly visible.

A concrete example of the applicability of this method is given in the map, Fig. 2.

The line *ABCDEF* represents a traverse down a spur, on the crest of which the strata are well exposed. On account of the lack of good exposure on the flanks of the spur, it is supposedly necessary to measure the stratigraphic column along the crest. Since in general the strike of the beds is not at right angles to the bearing of the traverse, the problem becomes complicated. However, if the bearings, inclinations and lengths of the various segments of the traverse, and the changing strikes and dips of the strata are kept, it is comparatively simple, in the office, to reduce these data to thicknesses by means of the nomograph. This case is only one of the many cases in which the nomograph would be useful, but it is one of the most striking.

In Mapping.

Interest in this problem came to the writer as the result of the converse of the above difficulties. A good columnar section of the beds surrounding a laccolith was at hand, but owing to a too brief field-season, certain boundaries were not recorded. Where one boundary of a formation was known as well as its thickness, strike and dip, and where it was possible from the contour map to get the slope of the ground, it was simple to get the mapping width of a given formation. By "mapping width" is meant the width of the horizontal projection of the outcrop of the formation.

In Mine Measurements.

In mines it is particularly difficult to get sections which are suitably oriented with respect to the workings to allow of direct measurement bed by bed. The geologist must follow the workings regardless of the angles at which they intersect the strata. In this case the nomographic method of solving the trigonometric equations for the thickness in terms of strike, dip, and the measurements of the traverse, is particularly advantageous. This fol-

lows from the fact that where the section is measured in a vertical shaft or horizontal drift one or two of the steps of the calculation are eliminated.

ADVANTAGES.

The chief advantage of the nomographic method is in saving of time. As proof of this the following experiment was made. The writer who is moderately accustomed to the use of the logarithmic slide rule, and rather more proficient in the use of logarithmic tables, solved a series of six problems; first by the nomograph, and then by logarithms. These problems were made up at random. This was done before he became familiar with the chart. The average time by the first method was one minute and forty-four seconds, a saving of one minute and thirty-four seconds over the three minutes and eighteen seconds average time by the logarithmic tables.

A further advantage is that no attention need be paid to the formula, nor to the theory on which it depends. All the necessary information as regards the sequence of the various steps and the manner in which they are made is given on the key chart, Fig. 5. Once the formula has been correctly derived, and properly incorporated in the nomograph no further attention need be paid it. In logarithmic calculation it is necessary to keep the formula at hand.

In the latter portion of this article the accuracy of this method is discussed and is shown to be of the same order as that of the angular measurements. In short, it is accurate enough where the directions are measured by hand instruments, and the distances are paced.

HOW THE NOMOGRAPH IS USED.

The following rules for the use of the nomograph are put as simply as possible, and with no attention to the theories on which they depend. The discussion of the theory of the nomograph and the trigonometric processes by which the formula is derived is left to a later portion of the article.

The rules are also expressed in a graphic form in Fig. 5, and are again indicated by the broken lines on the nomograph, Fig. 6.

There are five principal steps. In addition there are a few rules for exceptional cases in which the various angles reach limiting values.

Rules.

First.—By means of a straight edge project a line from the point representing the angle of dip on the upper left-hand scale to the point representing the slope on the upper right-hand scale. Call the intersection of this line on the middle scale "*m*" and note its value.

Second.—Project a line from the point representing the slope on the upper left-hand scale to the point representing the angle between the traverse and the strike on the upper right-hand scale. Call its intersection on the middle scale "*z*" and note it down.

Third.—Project a line from the point representing the value of "*z*" on the middle lower scale to the point representing the dip on the lower left-hand scale. Call its intersection on the second scale from the left "*n*" and note it down.

Fourth.—Find *R*, which is equal to the sum of "*m*" and "*n*" when the dip of the beds is against the slope, and which is equal to the difference of "*m*" and "*n*" when the beds dip with the slope.

Fifth.—Project a line from the point representing *R* on the lower right-hand scale to the point representing the length of the traverse on the middle lower scale. Its intersection on the second scale from the right is "*t*," the thickness of the strata crossed by the traverse.

Decimal Points.

In the first three steps the decimal points are cared for by the marking of the scale, except where certain angles are represented by dotted lines. In cases where these angles are used it is necessary to move the decimal point one place to the left. The angles represented by these dotted lines occur in the

formula as trigonometric functions whose value is between 0.1 and 0.01.

In the fifth step the decimal point is determined by inspection.

Special Cases.

Under certain special conditions one or two of the steps may be omitted; as follows:

"*m*."—The determination of "*m*" may be omitted in the following cases:

1. Where the surface on which the traverse is made is horizontal.
2. Where the dip of the beds is vertical.

"*z*" and "*n*."—The determination of "*z*" and "*n*" may be omitted in the following cases:

1. Where the surface on which the traverse is made is vertical, as in mine shafts or on cliffs.
2. Where the dip of the beds is horizontal.

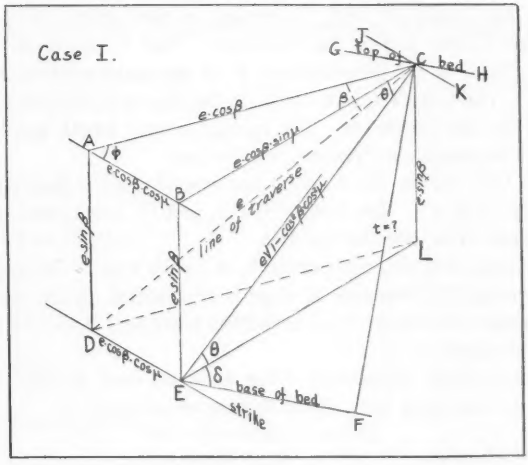


FIG. 3.

3. Where the direction of the traverse is parallel to the strike of the beds.

The reasons why these steps may be omitted are discussed in the section of the article on the theory.

THEORY.

Derivation of Formula.

Explanation of Diagram.—The diagram, Fig. 3, represents a solid of three dimensions. The lines *DE*, *AB*, and *JCK* are parallel to the strike of the beds whose thickness is to be measured; *DE* and *JK* represent respectively the lower and upper boundaries of the outcrop of the bed. The line *DC* represents the line along which the traverse is carried and its length e is the length of that portion of the traverse which crosses the bed. *DEL* and *ABC* are horizontal planes. *AC* is the projection of e on the plane *ABC*. Then the angle β (angle *ACD*) is its inclination from the horizontal, and the angle ϕ (angle *CAB*) is the angle between the bearing of the traverse and the strike of the bed. The plane *BCLFE* is normal to the strike and passes through *C*, one end of the traverse. Then θ (angle *BCE* or angle *CEL*) is the projection of β on the plane normal to the strike. The angle δ (angle *LEF*) is the dip or inclination of the beds from the horizontal. The line *CF*, whose length is t, is the true or perpendicular thickness of the bed.

The line *DC* on the diagram corresponds to the line *DC* on the map (Fig. 2). The lines *AB*, *DE*, and *JK* correspond to the unlettered strike lines on the map.

The angle ϕ is also represented by ϕ on the map. The angle β representing the steepness of slope is represented on the map by the number of contour lines crossed in travelling a unit of horizontal distance.

Trigonometric Argument.—The symbols used in the trigonometric reasoning have the following meanings:

β = inclination of traverse from horizontal,
ϕ = angle between strike of beds and bearing of traverse,

θ = projection of β on the plane normal to the strike,
δ = dip of the strata,
e = length of traverse,
t = the unknown quantity representing the thickness of the beds. It is a function of β, ϕ, δ, and e. The angle θ is used only as a stepping stone to get the formula.

$$AD/e = \sin \beta, \tag{1}$$
$$AD = e \cdot \sin \beta, \tag{2}$$
$BE = CL = AD = e \cdot \sin \beta$ (being parallel lines comprehended between two parallel planes), (3)
$$AC/e = \cos \beta, \tag{4}$$
$$AC = e \cdot \cos \beta, \tag{5}$$
$$AB/AC = \cos \phi, \tag{6}$$
$$AB = AC \cdot \cos \phi = e \cdot \cos \beta \cdot \cos \phi, \tag{7}$$
$$DE = AB = e \cdot \cos \beta \cdot \cos \phi, \tag{8}$$
$$BC/AC = \sin \phi, \tag{9}$$
$$BC = AC \cdot \sin \phi = e \cdot \cos \beta \cdot \sin \phi. \tag{10}$$

Then applying Pythagoras's theorem to the triangle CDE,

$$EC = \sqrt{(CD^2 - DE^2)} \tag{11}$$
$$= \sqrt{(e^2 - e^2 \cdot \cos^2 \beta \cdot \cos^2 \phi)} \tag{12}$$
$$= e \cdot \sqrt{(1 - \cos^2 \beta \cdot \cos^2 \phi)}. \tag{13}$$

And in the triangle EBC,

$$\text{Sin } \theta = BE/EC \tag{14}$$

$$= \frac{e \cdot \sin \beta}{e \cdot \sqrt{(1 - \cos^2 \beta \cdot \cos^2 \phi)}}. \tag{15}$$

Similarly,

$$\text{Cos } \theta = BC/EC = \frac{e \cdot \cos \beta \cdot \sin \phi}{e \cdot \sqrt{(1 - \cos^2 \beta \cdot \cos^2 \phi)}}. \tag{16}$$

Now in the triangle CEF,

$$t/EC = \sin(\delta + \theta), \tag{17}$$
$$t = EC \cdot \sin(\delta + \theta), \tag{18}$$
$$= EC \cdot (\sin\delta \cdot \cos\theta + \cos\delta \cdot \sin\theta). \tag{19}$$

Then, substituting from equations 13, 15, and 16, and letting $k = (1 - \cos^2\beta \cdot \cos^2\phi)$,

$$t = e \cdot \sqrt{k} \times \left(\frac{e \cdot \sin\delta \cdot \cos\beta \cdot \sin\phi}{e \cdot \sqrt{k}} + \frac{e \cdot \cos\delta \cdot \sin\beta}{e \cdot \sqrt{k}} \right) \tag{20}$$

$$= e \cdot \sin\delta \cdot \cos\beta \cdot \sin\phi + e \cdot \cos\delta \cdot \sin\beta \tag{21}$$
$$= e \cdot (\cos\delta \cdot \sin\beta + \sin\delta \cdot \cos\beta \cdot \sin\phi). \tag{22}$$

This gives the simplest form of the complete formula. On account of the large number of independent variables, it is necessary, when a graphic method is used, to solve this equation by several successive steps. The equation is broken up as follows:

Let $m = \sin\beta \cdot \cos\delta$, (23)
$z = \cos\beta \cdot \sin\phi$, (24)
$n = z \cdot \sin\delta = \cos\beta \cdot \sin\phi \cdot \sin\delta$, (25)
and $R = m + n = \sin\beta \cdot \cos\delta + \cos\delta \cdot \sin\beta \cdot \sin\phi$. (26)
Then, $t = e \cdot R$ (27)
$= e \cdot (m + n)$ (28)
$= e \cdot (m + z \cdot \sin\delta)$. (29)

The foregoing discussion deals only with the case where the dip of the strata is against the slope. This is called Case I.

There is a second case, Case II, in which the beds dip with the slope, and this has two sub-cases. These are as follows: Sub-case *A*, where the dip of the beds is greater than the slope, and Sub-case *B*, where dip of the beds is less than the slope. By "slope" is meant the inclination of the surface on which the traverse is made. The relations for these sub-cases are shown in Fig. 4.

Let us consider Sub-case *A*. In the figure the line *CE* is identical with *CE* of the diagram for Case I., and has the same value. Then:

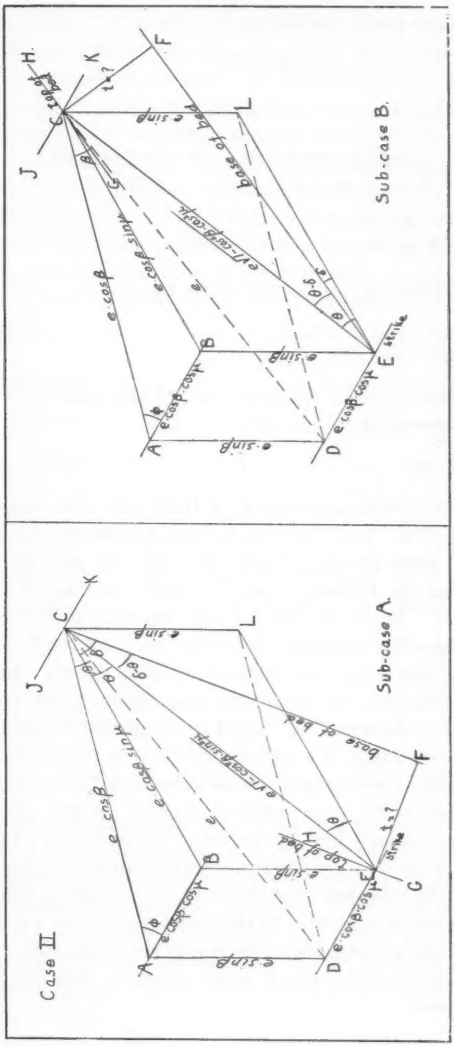

Case II
Sub-case A.
Sub-case B.
Base of bed
Top of bed
Strike
Dip
Apparent dip
Vertical thickness
e sin β
e cos β
e cos α sin γ
e cos α cos γ
e sin α
e cos α
e vertical thickness
A
B
C
D
E
F
G
H
J
K
L

FIG. 4.

$$t = e \cdot \sqrt{(1 - \cos^2\beta \cdot \cos^2\phi)} \cdot \sin(\delta - \theta). \tag{30}$$

Then letting $\kappa' = (1 - \cos^2\beta \cdot \cos^2\phi)$,

$$t = e \cdot \sqrt{\kappa'}(\sin\delta \cdot \cos\theta - \cos\delta \cdot \sin\theta) \tag{31}$$

$$= e \cdot \sqrt{k'}\left(\frac{e \cdot \sin\delta \cdot \cos\beta \cdot \sin\varphi}{e \cdot \sqrt{k'}} - \frac{e \cdot \cos\delta \cdot \sin\beta}{e \cdot \sqrt{k'}}\right) \tag{32}$$

$$= e \cdot \sin\delta \cdot \cos\beta \cdot \sin\phi - e \cdot \cos\delta \cdot \sin\beta \tag{33}$$

$$= e \cdot (\sin\delta \cdot \cos\beta \cdot \sin\phi - \cos\delta \cdot \sin\beta). \tag{34}$$

Then by substituting from equations 23 and 25,

$$R = m - n \tag{35}$$

and $$t = e(m - n). \tag{36}$$

By a similar process the equation for the value of "t" in Sub-case B is found to be

$$t = e(n - m). \tag{37}$$

The trigonometric significance of these last two equations is the same, for "n" and "m" are factors dependent on sines and cosines, and these are numerically the same for plus and minus angles. Thus the following rule for either sub-case of Case II may be made. Rule: Where the beds dip with the slope let R equal the numerical difference between "m" and "n."

Effect of Maximum and Minimum Values of the Angles.— Under the rules for the use of the nomograph given above, it was stated that the term "m" could be eliminated in cases where the traverse was made on a horizontal line or in horizontal drifts, or where the beds are vertical. This is because "m" is the product of the sine of the slope and the cosine of the dip. Since the sine of 0° equals zero, and the cosine of 90° is likewise zero, the presence of either of these factors would eliminate the product.

Similarly the statement that the term "n" could be eliminated where the traverse is parallel to the strike depends on the following. The angle between the traverse and the strike enters in this case as a sine function, which would be zero, thus making the whole term zero.

The rule that "n" can be eliminated where the slope on which the traverse is made is vertical follows from the fact that the slope enters the formula as a cosine. In this case zero is again introduced making the whole term zero.

The rule that "n" can be eliminated where the dip of the beds is horizontal, follows from the fact that the dip enters the formula as a sine. In this case zero is again introduced making the whole term zero.

Attention to the above will be called in the use of the nomograph, by the fact that these functions which would come in as zero are beyond the limits of the scale; they are in fact at infinity.

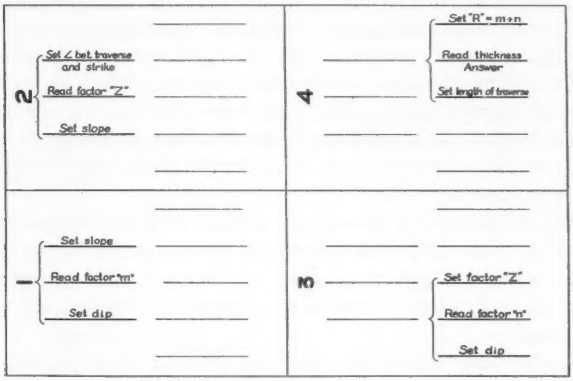


FIG. 5.

Principle of the Logarithmic Straight-Line Nomograph.

The logarithmic straight-line nomograph consists of three parallel lines marked off into spaces of various sizes. The lengths of the spaces thus marked off are proportional to the mantissas of the logarithms of the numbers opposite their terminals. In the simplest case the marking is identical with that of a slide rule. In more complicated cases the markings are proportional to the logarithms of various functions, such as the trigonometric functions of angles.

In multiplying by the slide rule distances proportional to the logarithms of factors are added, and opposite the end of the last distance is found the product of the numbers. In multiplying by such straight-line nomographs as are here given, a line is drawn or projected between the two points on the outer scales representing the two factors. This line cuts the middle scale at a point whose distance above the base of this scale is half as much as the sum of the distances representing the factors. Now if the middle scale is also a logarithmic scale but with its unit length half that of the outer scales, the intersection point will indicate the product of the two factors.

In the chart, Fig. 6, the right-hand scale of the upper row is made with its abscissas proportional to the logarithms of the sines of angles from 1° to 90°. The left-hand scale in this row is made with its abscissas proportional to the logarithms of the cosines of angles from 0° to 89°, inclusive. The fact that $\sin A = \cos (90° - A)$ is brought out by the fact that the height of any angle on one scale is the same as the height of its complementary angle on the other scale.

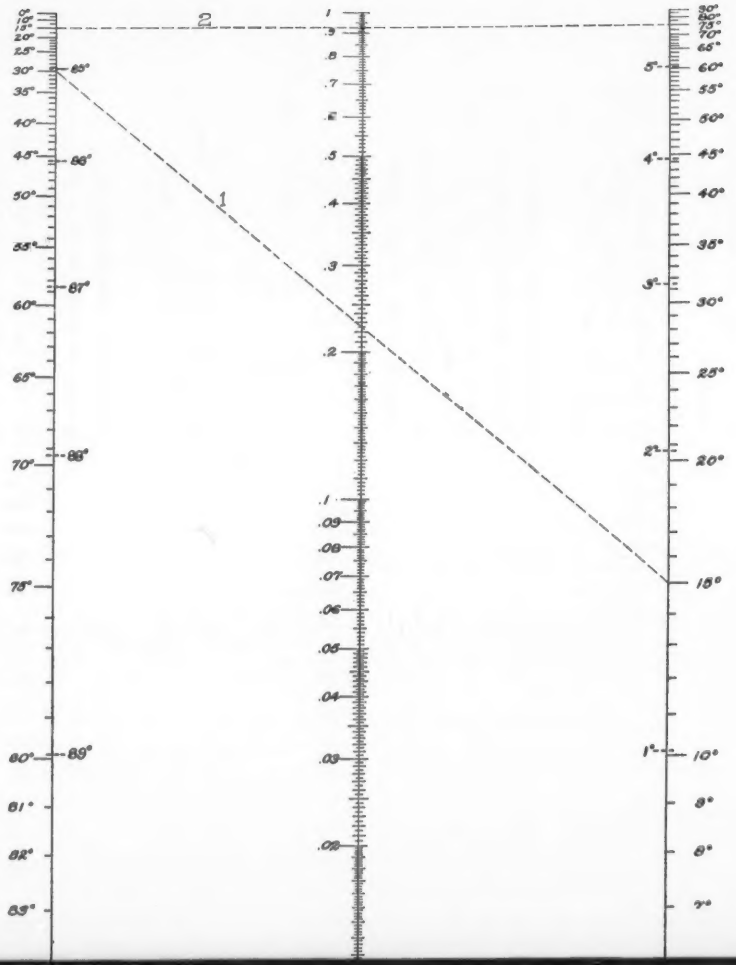
The middle scale of the top row is made with its divisions proportional to one-half of the logarithms of various numbers so that intersections on it give the products of sines multiplied by cosines. The decimal points in the index figures are correct for the products.

The left-hand scale in the lower row is similar to the right-hand scale of the upper row, its abscissas being made proportional to logarithmic sines.

The middle scale in the lower row is made with its abscissas proportional to the logarithms of numbers.

The second scale from the left in the lower row is made with its abscissas proportional to one-half of the logarithms of numbers, so that intersections on it give the product of a number taken on the middle scale and a sine taken on the left-hand scale.

The right-hand scale on the lower row is similar to the middle scale on this row so that its abscissas are proportional to logarithms of numbers.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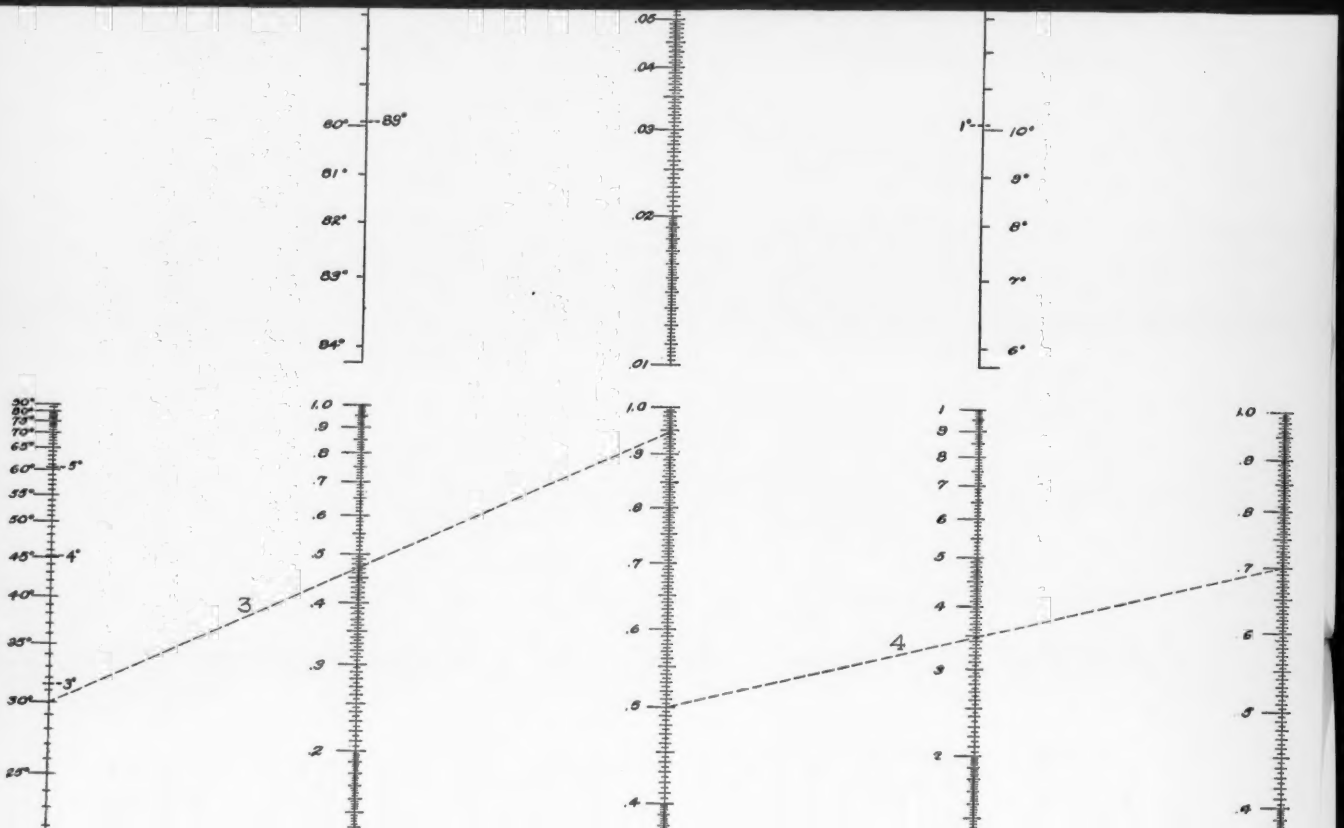
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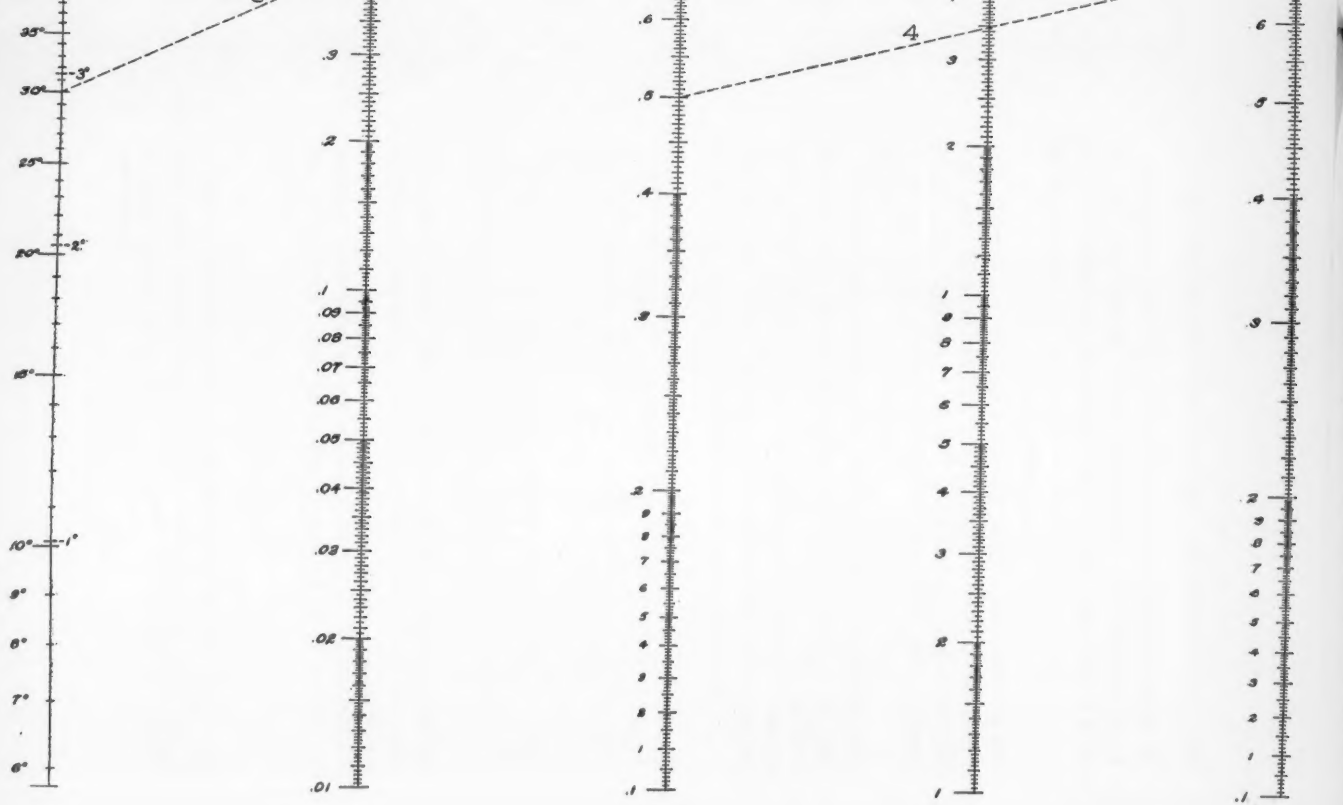
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FIG. 6.

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The second scale from the right is like the second scale from the left (and also like the middle upper scale). Intersections on it give the product of the numbers taken on the right-hand and on the center scales.

Accuracy.

In order to test the accuracy of the method half a dozen problems were taken at random and worked out both by the nomograph and by logarithms. All of these problems come under Case I., the dip being against the slope. The results are tabulated below.

The hypothesis was made that the logarithmic calculations were perfectly accurate and the nomographic calculations were compared with these in order to determine the error. Disregarding the plus and minus character of the various errors their mean is 0.75 per cent. The error is less than the allowable error in pacing or in taking angular measurements with hand instruments.

Problem No.	1	2	3	4	5	6
Dip of beds.....	16°	50°	48°	33°	42°	80°
Slope of traverse..	10°	15°	12°	24°	30°	17°
Angle ϕ	50°	80°	79°	85°	83°	30°
e.....	565 ft.	428 ft.	27 ft.	1,283 ft.	764 ft.	88 ft.
Thickness:						
By chart	222 ft.	403 ft.	22.2 ft.	1,077 ft.	669 ft.	45.1 ft.
By logs.....	221 ft.	406 ft.	22.2 ft.	1,074 ft.	678 ft.	45.9 ft.
Error	+ 1 ft.	− 3 ft.	0.0 ft.	+ 3 ft.	− 9 ft.	− .8 ft.
Per Cent. Error ...	+.5 %	−.7 %	0.0 %	+.3 %	−1.3 %	−1.7 %

A great opportunity for error comes in with the logarithmic method as it is very easy to miscopy the figures from the tables, and it is also easy to make a mistake in adding the logarithms together. An error of one unit, if it occurs in the first place of the characteristic, may throw the answer out by as much as ten per cent.

Sources of Error.

Sources of error in the nomographic method are of two principal sorts; namely, those inherent in the diagram, and those due to inaccuracies on the part of the user. They may be tabulated as follows:

A. Inherent errors.

1. The divisions of the scales may be faulty due to,
   (*a*) Carelessness of the draughtsman.
   (*b*) Inevitable close grouping of values as at the top of the sine and cosine scales, where a difference of five degrees is represented by a very short distance. Here it is impossible to plot individual degrees unless the whole chart is made very large.
   (*c*) Reproduction by photographic processes may introduce errors in spacing due to the foreshortening effect of lenses whose field is not perfectly flat.
2. The spacing of the scales relative to one another may be inaccurate; *i. e.*, the middle one of a group of three scales may not be exactly half way between the two outer scales.

B. Errors by the calculator.

1. The scales may be misread and a wrong value used.
2. Interpolation where the distance between adjacent marked points is great may be inaccurate.
3. The calculator may not place his straight-edge accurately, though he may intend the correct point.

Fortunately most of these errors are halved at the point where the straight-edge cuts the middle scale of any group.

Errors due to mistakes in the original field measurements are, of course, not eliminated by this method of calculation; and they are eliminated by no other method.

CONCLUSIONS.

The writer believes that the nomographic method of calculating thicknesses has advantages of speed over the direct trigonometric method or the methods of descriptive geometry, where the strike and dip of the beds and the length, bearing, and inclination of a traverse across them are known.

The accuracy of the nomographic method is comparable to the accuracy of the direction measurements, for these can not be made closer than about one degree with a hand compass and clinometer. Furthermore, the accuracy of the nomographic method is comparable to the accuracy of paced length measurements. Though it is not comparable to the accuracy of taped measurements, this fact does not militate against the use of this method, as the errors due to inaccurate direction measurements are comparatively great.

SHEFFIELD SCIENTIFIC SCHOOL,
NEW HAVEN, CONN.

WOLFRAMITE AND SCHEELITE AT LEADVILLE, COLORADO.

By R. S. Fitch and G. F. Loughlin.[1]

INTRODUCTION.

The latest of the many types of ore bodies to be recognized in the famous district of Leadville, Colorado, is that of gold-bearing quartz-pyrite veins containing the tungsten minerals wolframite and scheelite. The first of this material recognized was sent by Mr. Fitch to the U. S. Geological Survey in the fall of 1914, and more material was obtained by him in August, 1915. There has been no opportunity to study the geology of the deposit in detail, but the presence of the tungsten minerals is believed to be of sufficient interest to warrant this preliminary description.

The ore from which this material was taken is being mined in a number of leases on the Ibex and adjoining properties to the south, on Breece Hill. Production at present is from Nonie, Ontario, and Capitol claims, while practically identical material in every way except value, has been opened in a shallow shaft on the St. Paul group. The ore production ranges from 200 to 250 tons per day and average controls on car shipments would average 0.8 oz. gold and 0.5 oz. silver per short ton. Shipments go to all Colorado smelters except that at Durango. The minimum value for profit under present smelting contracts is about $12 per ton. A large tonnage of ore of lower grade is known to exist and for its treatment a 200-ton mill is proposed. The gold is thought to be largely free, possibly coating the fractures in the pyrite crystals, since it has been determined that the large unfractured crystals, to be described later, are of low value.

[1] Published by permission of the Director of the U. S. Geological Survey.

COUNTRY ROCK.

The country rock in the vicinity of the deposits includes Weber grit and gray porphyry, and the veins may cut both. In the specimens studied, the wall rock is so much silicified and pyritized that its identity is somewhat doubtful, but it is certainly grit in part, whereas no porphyritic texture could be identified. The two thin sections studied of the wall rock are both of grit, silicified and pyritized. The grit is composed mostly of subangular grains of quartz and a few grains resembling completely sericitized feldspar, in a fine matrix of sericite and minute quartz grains. Secondary quartz is also present in veinlets or impregnating clusters and grains. It can usually be distinguished from primary quartz by the absence in it of strain effects. A few larger flakes of sericite, up to half a millimeter in length, are present and are clearly of secondary origin. Pyrite is scattered prominently through the rock in grains up to 2 millimeters in diameter. The larger grains of it are more or less intergrown with secondary quartz and sericite.

Close by, or between, some of the veinlets, the grit may be so thoroughly recrystallized as nearly to lose its identity, even under the microscope. The numerous originally small grains of quartz and sericite have been transformed into relatively few larger grains of the same minerals. These larger grains of quartz and sericite are more or less intergrown with each other and with pyrite, relations identical with those among the same minerals in the vein proper.

VEINS.

The veins, or vein zones, strike N. 33° E. and dip 68° W., and so far as developed lie wholly to the east of the Weston fault. Their relations to this fault have not been determined. In the specimens studied they fill anastomosing fractures enclosing fragments of wall rock, and contain numerous vugs into which the well-crystallized termination of the vein minerals project.

The worked payable portion forms a shoot of ellipsoidal out-

line. Its rough dimensions at the 500-foot level are 120 feet in width and 130 feet in length; on the 900-foot level, 40 feet in width and 150 feet in length. On the second level, for a distance of 40 to 50 feet, a well-defined foot wall can be seen which is accompanied by a thin gouge. Elsewhere on this level the drift curves while following the pay material and shows clearly the elliptical shape. In general, distinct walls are not apparent, and the pay ore grades into material of exactly similar appearance but of low value. Tungsten minerals are distributed throughout the zone of higher grade ore, and persist downward with the shoot, their percentage increasing markedly with depth. The scheelite, however, is more abundant on the upper levels, and the wolframite on the lower.

The principal minerals in the veins are quartz, pyrite, wolframite and scheelite. Sericite, in parallel growth with quartz, forms films along the fracture walls.

Quartz.—The quartz occurs mostly in typical colorless crystals, up to two inches in length, which line cavities and also protrude through, or penetrate pyrite crystals. In certain places where the crystals are crowded together, the quartz has a rather massive, milky appearance. In only one specimen was any dense, or cherty, quartz noted. This formed a short veinlet about two and one half inches long, and evidently represented an extreme degree of silicification along a small fracture. It was closely associated with the well crystallized quartz, and contained minute pyrite crystals. It was doubtless formed at the same time as those minerals.

Pyrite.—Pyrite is well distributed throughout the veins, and occurs mostly in groups of rather large crystals. Single crystals of cube form have been found with edges five inches long. Where crystal faces have formed, the pyritohedron and cube prevail in combination, while small faces representing the trapezohedron, diploid, and octohedron bevelling edges and corners of the crystal are also present. An interesting phase has been the repeated development of narrow pyritohedron faces on a large cube face giving, especially where corroded, a "Gothic window"

shape of marking. Besides the parallel growth with quartz already mentioned the pyrite exhibits in places a marked intergrowth with wolframite. Parallel growth with scheelite, though noted, is not common.

Wolframite.—Wolframite is not prominent in every specimen examined, but tends to occur in masses of dull brownish black color, which terminate abruptly in the vein against pyrite and quartz, or against scheelite. These masses contain many small cavities, where some faces and angles of wolframite crystals have developed, but these are generally so corroded that no adequate idea of the crystal form can be gained. In one specimen, however, there is an isolated crystal over half an inch long, projecting into a small vug. The crystal is of flat rhombic or wedge-shaped outline. The broad faces are those of the clinopinacoid *b* {010} as they are parallel to the perfect cleavage. The narrow faces are the orthopinacoid *a* {100} and probably the steep dome *t* {102}. No other faces are represented on this crystal. The surfaces of small crystals in other specimens are too much corroded to permit the determination of crystal faces. Some faces that are not corroded are rather strongly striated, the striations probably lying parallel to the prism zone. The hardness is apparently as low as 3, since even glistening surfaces are scratched by calcite. This low value may be due in part to the corrosion of the mineral, but may also be characteristic of the manganese tungstate hübnerite in contrast to the iron tungstate ferberite, whose hardness is given by Dana[2] as 5 to 5.5. The luster, though dull for the masses as a whole, is submetallic on cleavage surfaces and uncorroded crystal faces. The color, though prevailingly brownish black, is dark reddish on thin, translucent cleavage flakes. Thin flakes under the microscope are red to yellow. The streak is chocolate brown to reddish brown. No quantitative analysis of the mineral has been made, but qualitative tests prove it to contain considerable amounts of manganese and tungsten. These results agree with the low hardness (3) and partial transparency in indicating that the mineral belongs to the hübnerite or manganese tungstate part

[2] Dana, E. S., "System of Mineralogy," 6th ed., p. 983.

of the wolframite series, as contrasted with ferberite, the iron tungstate, which is harder (5) and opaque.[3]

The wolframite masses contain numerous small grains of pyrite, some of which are intimately intergrown with wolframite. The intergrowths consist of bladed or tabular individuals of wolframite in diverging groups, and separated one from another by thin layers of pyrite. Wolframite comprises two thirds to three fourths of the intergrowth. Wolframite is also intergrown on a small scale with scheelite in the central parts of certain scheelite crystals.

Scheelite.—The scheelite occurs in localized aggregates, some closely associated with masses of wolframite, others with pyrite and quartz. In some places, massive scheelite is surrounded by massive pyrite; in others, scheelite crystals, growing on quartz or pyrite crystals, line vugs. The crystals are imperfect doubly terminated pyramids of the tetragonal system, truncated by narrow pyramid faces of the second order. Pyramidal cleavage surfaces are distinct, though not prominent. The hardness lies between 4 and 5, the luster is resinous to adamantine, and the color is rather light brown in the larger crystals to pale yellowish in small translucent grains. The crystal surfaces show no conspicuous effects of corrosion. They are free from intergrowths other than those with wolframite already mentioned, and grow upon all the other minerals in the veins.

Paragenesis.—The relations, already described, of the vein minerals to one another indicate that, while there were overlaps in the periods of growth, the general order of deposition was as follows: (1) Sericite, quartz, and pyrite in parallel growth, the sericite forming only at the beginning of the stage; (2) pyrite and wolframite, the latter predominating; (3) very little pyrite, a little wolframite and abundant scheelite, the scheelite continuing to form after the other two minerals had ceased. According to Hess[4] this seems to be the usual paragenetic relation of scheelite

[3] The chemical properties of the hübnerite and scheelite described in this paper have been verified by Mr. Frank L. Hess, and the physical properties by Mr. W. T. Schaller, both of the U. S. Geological Survey.

[4] Hess, F. L., and Schaller, W. T., "Colorado Ferberite and the Wolframite Series," U. S. Geol. Survey Bull. 583, p. 12, 1914.

to wolframite, or ferberite, in tungsten veins. These relations of the vein minerals are expressed in the following diagram (Fig. 7).

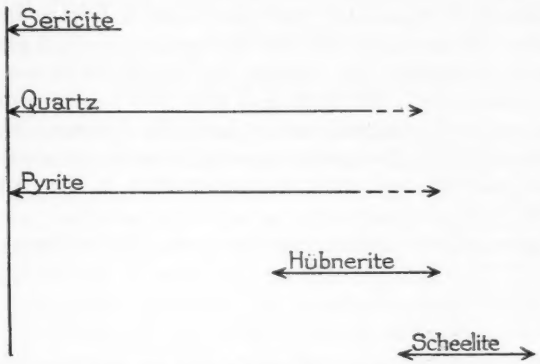


FIG. 7. Diagram showing order of deposition of minerals in tungsten-gold veins, Leadville, Colorado.

Relations to Other Types of Ore Bodies.—Veins containing tungsten minerals are as a rule found near intrusive igneous bodies, mostly granites and quartz monzonites, from whose magmas the vein minerals are believed to have been derived,[5] and the presence of tungsten minerals, especially members of the wolframite series, is regarded as a strong indication that the veins were deposited at high temperature characteristic of the deep vein zone.[6] The veins here described are near a large intrusive body of gray porphyry (quartz-monzonite porphyry), and also near ore bodies in the Ibex mine which have the mineralogic characters of contact-metamorphic deposits. They also lie in a part of the district characterized by strong sulphide veins with high gold-silver values, such as the Luema, whose mineral composition (zinc-blende, galena, pyrite, and chalcopyrite in a quartz gangue) indi-

[5] *Idem.*, p. 14.

[6] Emmons, W. H., "Genetic Classification of Minerals," ECON. GEOLOGY, Vol. 3, pp. 621 and 622, 1908. Ferguson, H. G., and Bateman, A. M., "Geologic Features of Tin Deposits," ECON. GEOLOGY, Vol. 7, pp. 229 and 230, 1912.

cates deposition at moderate depths.[7] These relations strongly suggest that the tungsten veins at Leadville represent a transition stage between contact-metamorphic deposits and the gold-silver sulphide veins. Hess states[8] that "silver seems to occur in greater quantity with the wolframites than does gold, and gold in greater proportional quantity with scheelite, but this can not be stated as an invariable rule." The presence of gold, up to nearly one ounce to the ton, in the tungsten veins at Leadville, does not add any definite evidence in this connection, as the two minerals, wolframite and scheelite, are about equally abundant in the material studied.

[7] Lindgren, W., "The Relation of Ore-Deposition to Physical Conditions," ECON. GEOLOGY, Vol. 2, p. 113, 1907.

[8] *Op. cit.*, p. 13.

THE RÔLE OF COLLOIDAL MIGRATION IN ORE DEPOSITS.

JOHN D. CLARK AND P. L. MENAUL.

During a study of the enrichment of copper sulphide ores[1] it was observed that the natural sulphides and sulpho salts of copper readily became colloidal when placed in solutions of mild alkalinity and subjected to the passage of hydrogen sulphide through these solutions. It was noticed that when the hydrogen sulphide escaped, or was in other means eliminated, that these colloidal materials became coagulated, and ceased to exist as colloids. It was also found that the presence of salts of aluminum and of calcium, and even the nearly insoluble calcium carbonate, and the very insoluble aluminum oxide, caused the colloidal materials to flocculate and precipitate.

Knowing, as we do, that the ore-bearing solutions which come from some of our intrusive rocks are alkaline and that they are charged with hydrogen sulphide, it seemed that in the case of sulphides and sulpho salts of copper, that these minerals might have been brought up in the form of colloids, so very highly dispersed that they could penetrate deeply into the most minute fissures, cracks and pores, and that when the hydrogen sulphide had escaped, or had been chemically assimilated, these colloidal sulphides had been coagulated and had formed the massive sulphides of the deposits. Also as it was seen that calcareous and argillaceous materials had the power, apparently by their presence, to cause a deposition of these copper minerals from their colloidal condition, it appeared that the numerous limestone replacements of copper ores, and the frequently occurring copper deposits in shales

[1] John D. Clark, "A Chemical Study of the Enrichment of Copper Sulfide Ores," *Bull. University of New Mexico*, Chem. Series, Vol. I., No. 2, 1914. See also C. F. Tolman, Jr., and John D. Clark, ECON. GEOL., Vol. IX., No. 6, pp. 559–592, 1914.

and clay gouges, might be accounted for by this process of colloidal migration and later precipitation.

With a view of ascertaining whether other minerals would behave in a manner similar to the behavior of those of copper, thus showing the possibility of all important metallic minerals migrating in the colloidal condition and later depositing in ore bodies, the following experiments were conducted. A number of natural minerals were chosen, each was separated from impurities as far as could be done with the aid of a lens, and a gram of each was passed through a 200-mesh screen, placed in a 200 c.c. gas-washing bottle, and covered with 100 c.c. of $N/100$ potassium hydroxide. The contents of each bottle were shaken, and it was observed that in each case the powdered mineral settled inside of two minutes. These bottles were connected with each other, placed in a darkened basement, and hydrogen sulphide was allowed to pass intermittently through the solutions in the gas washing bottles for two months and seven days. At the end of six days, during the period in which hydrogen sulphide was being passed through the bottles, the solutions began to appear cloudy, and at the end of two weeks it was observed that in certain bottles a great deal of the mineral had dispersed.

At the end of two months and seven days each bottle was shaken and allowed to stand undisturbed for five minutes. As all of the powdered minerals had settled within two minutes before the passage of the hydrogen sulphide it was assumed that any material remaining suspended at the end of five minutes was in the colloidal condition. Following this settling of five minutes the upper 90 c.c. of the solution in each bottle was carefully siphoned from the bottle and analyzed. With the exception of argentite and proustite, a portion of each of the minerals was found to have gone into the colloidal condition.

The results of the experiment are here tabulated:

TABLE I.

Mineral.	Amount in Suspension.	Percentage of Mineral in Suspension.
Arsenopyrite	0.1582	15.82
Cobaltite	0.0971	9.71
Pyrite (in N/1000 KOH)	0.2013	20.13
Cinnabar	0.0872	8.72
Pyrrhotite	0.0222	2.22
Stannite	0.2977	29.77
Enargite	0.2187	21.87
Sphalerite (in N/1000 KOH)	0.1588	15.88
Tetrahedrite	0.0316	3.16
Stibnite	0.0479	4.79
Argentite	none	none
Smaltite	0.1672	16.72
Orpiment	0.0506	5.06
Covellite	0.2888	28.88
Niccolite	0.1431	14.31
Proustite	none	none
Bornite	0.0379	3.79
Realgar	0.2471	24.71

Each of the colloids became less dispersed when hydrogen was passed through the solution for the purpose of driving out the hydrogen sulphide.

Having found that these minerals readily became colloidal in solutions not unlike those coming from igneous intrusions, it became of interest to discover the effect of limestone and of argillaceous material upon the dispersed minerals.

With this in view another series of gas-washing bottles were prepared with the same minerals and with $N/100$ potassium hydroxide exactly as in the previous experiment, but with the addition of a small piece of fused aluminum oxide of about one gram in weight. This was hung just below the surface of the liquid in each bottle by means of a fine platinum wire. These bottles were placed in a darkened basement, were connected with a hydrogen sulphide generator, and for a period of two months, hydrogen sulphide was allowed to pass intermittently through their contents. The minerals became colloidal, but a portion of the dispersed material in each bottle gathered upon and adhered to the aluminum oxide. The lumps of aluminum oxide were

removed, washed with distilled water and determinations were made of the amounts of mineral which had deposited upon each. Table II. shows the results:

TABLE II.

Mineral.	Weight of Mineral Adhering to Aluminum Oxide.	Percentage of Mineral Adhering to Aluminum Oxide.
Tetrahedrite	0.0252	2.52
Arsenopyrite	0.0232	2.32
Cobaltite	0.0138	1.38
Cinnabar	0.0096	0.96
Sphalerite	0.0036	0.36
Realgar	0.0191	1.91
Bornite	0.0115	1.15
Galena	0.0121	1.21
Pyrite	0.0232	2.32
Chalcocite	0.0130	1.30
Stibnite	0.0140	1.40
Stannite	0.0064	0.64
Argentite	0.0002	0.02
Covellite	0.0280	2.80
Pyrrhotite	0.0169	1.69
Enargite	0.0253	2.53

Again a series of gas washing bottles were prepared as above described, and just below the surface of the liquid in each a piece of limestone weighing approximately one gram was suspended by means of a fine platinum wire. Hydrogen sulphide was passed through these bottles as described above and at the end of two months the amount of material adhering to the limestone lumps was determined. The results are here tabulated:

TABLE III.

Mineral	Weight of Mineral Adhering to Limestone.	Percentage of Mineral Adhering to Limestone.
Tetrahedrite	0.0133	1.33
Arsenopyrite	0.0101	1.01
Cobaltite	0.0083	0.83
Cinnabar	0.0070	0.70
Sphalerite	0.0020	0.20
Realgar	0.0075	0.75
Bornite	0.0062	0.62
Galena	0.0068	0.68
Pyrite	0.0100	1.00
Chalcocite	0.0068	0.68

Stibnite	0.0070	0.70
Pyrargyrite	0.0091	0.91
Stannite	0.0032	0.32
Argentite	none	none
Covellite	0.0140	1.40
Pyrrhotite	0.0084	0.84
Enargite	0.0135	1.35

It is to be noted that the amount of material which gathered upon the limestone is less than the amount which adhered to the aluminum oxide. This can be explained, for, as the passage of hydrogen sulphide continued, limestone went into solution and after a time all dispersion was inhibited by the presence of the solution of the calcium salt. Had the colloidal material in suspension been so arranged that any calcium salt forming from the limestone had been removed and thus could not come in contact with the colloids, as would be the case if ore bearing solutions were passing upward through fissures in limestone, it seems as if the limestone lumps would have, in time, become entirely replaced by the deposited materials.

Conclusion.

The experimental work done shows that nearly all of our important sulphide, arsenide and sulpho salt minerals, in their massive and crystalline forms, may become highly dispersed as colloids under the influence of hydrogen sulphide in solutions of mild alkalinity. These minerals are then in condition to migrate with these solutions or with the gas currents which pass through the solutions.

With the escape or assimilation of the hydrogen sulphide the minerals are precipitated out of the colloidal condition.

When colloidal solutions of these minerals come in contact with calcareous or argillaceous material, precipitation of the mineral occurs, and at least in the case of limestone contact, there is replacement.

The work indicates the possibility that the process of formation of ore deposits may be accounted for by simple physical chemical processes instead of by those involving complex chemical reactions.

University of New Mexico.

ALUMINUM HYDRATES IN THE ARKANSAS BAUXITE DEPOSITS.

D. C. Wysor.[1]

GENERAL.

It will be recalled that bauxite was discovered in Arkansas in the early "90's." The find was made by Dr. J. C. Branner, who was then at the head of the Arkansas State Geological Survey. Since the date of this initial discovery the ore bodies have been described in more or less detail by Branner, Williams, Gibbons, Hays, Mead and others. Professor Mead has had better opportunity than any one else, probably, for studying the deposits in detail, and those who have not read his most excellent article on the subject will do well to consult it in Economic Geology, Vol. X., No. 1, 1915.

The writer has been so fortunate as to have had considerable experience in the field in question, with the view of studying the geological and mining conditions. As a result of certain labors along the line of the former subject, important amounts of the mineral diaspore were discovered, and its relations, in part at least, to the other aluminum hydrates were established. As yet it has not come to my attention that this mineral has ever been mentioned as occurring in American bauxite deposits.

The prime purpose of this article, then, will be to describe in a very brief manner the various hydrated forms assumed by the alumina. No attempt will be made at any possible commercial considerations, but simply touch the subject from a scientific standpoint.

For a clearer understanding of the topic a hasty review is presented of the commercial types of aluminum hydrates as outlined by Dana and also summarize the major physical types of ore as found in the Arkansas field.

[1] Geologist, General Chemical Co., 25 Broad St., N. Y.

FORMS OF ALUMINUM HYDRATES.

	System.	Composition.	Luster.	Hard.	Sp. Gr.
Gibbsite..	Monocl.	$Al_2O_3.3H_2O$	Pearly to vitreous	2.5–3.5	2.3–2.4
Bauxite..	——	$Al_2O_3.2H_2O$	——	——	2.55
Diaspore.	Ortho.	$Al_2O_3.H_2O$	Brilliant	6.5–7	3.3–3.5

All students of the subject are familiar with the origin of these mineralogical names and are aware of the fact that the term bauxite is generally applied to commercial deposits of aluminum hydrate irrespective of whether they are chiefly tri-, di-, or monohydrate type. As a matter of fact gibbsite is probably the chief hydrate in practically all commercial occurrences, and as far as the writer is informed there is no lower hydrate in any of the American localities with the exception of the Arkansas field.

FORMS OF ARKANSAS BAUXITE.

There are three chief physical types of ore described as granitic, massive and oölitic.

The granitic ore, which is frequently very porous, takes its name from the granitic structure preserved as a result of its having weathered in situ from granitic structured syenite. The massive form is commonly a soft compact ore in which the original granitic structure is wholly or partly destroyed. The oölitic type, which has resulted from one or both of the other forms, consists of relatively small concretionary-like structures whose composition may or may not be similar to the hydrate matrix in which they are embedded.

With certain of these oölites only has the mineral diaspore been found, and it is the writer's belief that in all other cases gibbsite is the essential compound.

It has not been my good fortune to study any of the ores in thin section, but for all practical purposes we may consider them amorphous. During the process of alteration to hydrate of alumina, many of the feldspar crystals of the syenite have retained their general outlines, but it cannot be said that there is a well-developed crystalline structure indigenous to the ore.

CHEMICAL AND MINERALOGICAL CALCULATIONS.

In an ordinary chemical analysis of Arkansas bauxite we usually express "Loss on ignition," indicated in this paper as H_2O, and the oxides of silicon, titanium, iron and aluminum, the latter compound being determined by difference. It is not practical to consider in the usual analysis small fractional percentages of rarer constituents.

Relative to the mineralogy in general, the writer has found by repeated experiments that the accessory compounds herein quoted are essentially correct. For instance, there is little free silica in the ore, practically all being combined as in kaolinite, halloysite or related hydrous aluminum silicates. There are probably several forms in which the titanium occurs, but the one given appears most logical from studies made on the mineralogy and chemistry of the titanium compounds. There is strong evidence in favor of most of the iron existing as limonite, though it is frequently present as siderite, and less often as pyrite and magnetite.

It is to the aluminum compounds, however, that I wish to give special attention. From an inspection of the following tables it is certain that there are present the tri- and mono-hydrates, but it is a question as to the existence of the di-hydrate. It is obvious that we can assume proper mixtures of gibbsite and diaspore that will give any of the results submitted. In other words is there really such a compound as bauxite? With no crystalline structure as a guide what right have we to assume that the di-hydrate is present in any of the combinations studied? In reply we must admit that there is no absolute proof of its existence, but from both a practical and a theoretical point of view the writer sees no reason for not granting its presence.[2]

[2] The following is offered for the consideration of those who may not be thoroughly familiar with the literature on bauxite.

The writer has not examined all of the published articles on aluminum hydrate (bauxite, laterite, etc.) but in every case noted on foreign occurrences where the author has had occasion to discuss the properties of gibbsite, bauxite and diaspore, the existence of the second mineral has been very flatly denied or held to be highly problematical.

TABLE I.

SPECIAL SAMPLES OF OÖLITES AND MATRICES.

S'ple.	Form.	Color.	Luster.	Structure.	Fracture.	Streak.	Hard's.	Sp. Gr.
1[a]	Oölite	Red	Dull	Massive	Smooth	Chestnut brown	4	2.43
2[a]	Matrix	Gray	Dull	Massive	Smooth	Wood brown	4	2.35
3[b]	Oölite	Red	Dull	Massive and porous	Hackly	Honey yellow	2 to 4	2.42
4[b]	Matrix	Red	Dull	Massive and oölitic	Hackly	Honey yellow	2 to 4	2.36
5[c]	Oölite	Red	Dull	Massive	Smooth	Brownish red	4	2.41
6[c]	Matrix	Buff	Dull	Massive	Hackly	Yellowish brown	4	2.38
7[c]	Oölite	Black	Vitreous	Massive	Conchoidal	Brownish black	6 to 7	3.01
8[d]	Oölite	Buff	Dull	Porous	Hackly	Ocher yellow	2 to 3	2.41
9[d]	Matrix	Gray	Dull	Porous	Hackly	Greenish yellow	2 to 3	2.38
10	Oölite	Brown	Vitreous	Massive	Conchoidal	Reddish brown	5 to 6	2.77
11	Oölite	Black	Vitreous	Massive	Conchoidal	Grayish black	5 to 7	2.93
12	Oölite	Red	Subvit.	Massive	Hackly	Wood brown	1 to 5	2.48
13[e]	Oölite	Brown	Subvit.	Massive	Smooth	Grayish brown	4 to 5	2.53
14[e]	Oölite	Red	Dull	Massive	Hackly	Red	4	2.43
15[e]	Oölite	Red	Dull	Massive	Hackly	Hair brown	4	2.40
16[e]	Oölite	Brown	Vitreous	Massive	Conchoidal	Chocolate	5 to 7	2.78
17	Oölite	Brown	Vitreous	Massive	Conchoidal	Chocolate	4 to 6	2.69
18	Oölite	Red	Subvit.	Massive	Smooth	Red	4 to 5	2.55

Note.—Samples with same exponent came from same specimen of ore.

In nearly all cases a sharp line of division, optically, is to be noted between oölites and matrices, but physically the actual parting of the two is difficult.

Oölites are not usually uniform throughout. The outer portions are commonly composed of concentric layers of various colors, these being of different color and hardness from inner portions.

Oölites usually sever when a specimen of ore is broken.

Sir Thomas Holland, in writing on the Indian laterites, states that there is no such mineral as bauxite but that the so-called "double hydrate" is simply a mixture of gibbsite and diaspore.

Professor Lacroix regards the di-hydrate as consisting of various colloidal hydrates of aluminum mixed with such impurities as iron hydroxide, clay, sand, etc. So with Messrs. H. and F. H. Warth and others we find that they give exceedingly small, if any, credit to the existence of bauxite as a distinct mineral with definite, physical and chemical properties.

To my knowledge, Professor Mead is the only author, except the writer, who has suggested the presence of bauxite in association with gibbsite in American deposits. Professor Mead holds, however, that both bauxite and gibbsite in the Arkansas field are essentially the same chemically, each approximating the formula $Al_2O_3.3H_2O$, but that they differ physically in that the former is amorphous and the latter crystalline. To sum the whole situation, it may be said that no one has yet offered any absolute proof of the presence or absence of bauxite as a mineral, and though indisputable evidence one way or the other may not be of practical value, it would be welcomed from a scientific point of view.

It seems entirely plausible that in the development of the lower hydrates, which certainly are of secondary origin, that chemically combined water was spontaneously expelled from the original gibbsite which was unstable under the existing conditions. Furthermore it appears entirely logical to consider that during the reduction to lower hydrates both molecules of water were not expelled simultaneously, but alternately, thus giving rise to the intermediate member, bauxite.

TABLE II.

CERTAIN CHARACTERISTICS OF OÖLITES AND MATRICES.

Sample.	Hardness.	Sp. Gr.	H_2O.	SiO_2.	TiO_2.	Fe_2O_3.	Al_2O_3.
(OÖLITES.)							
7	6 to 7	3.01	14.58	2.20	1.70	9.00	72.52
11	5 to 7	2.93	17.66	1.54	2.00	10.70	68.10
10	5 to 6	2.77	19.62	2.52	2.20	11.50	64.16
17	4 to 6	2.69	20.42	3.32	2.00	9.80	64.44
18	4 to 5	2.55	26.02	3.48	2.40	7.40	60.70
13	4 to 5	2.53	27.54	3.76	2.70	5.70	59.30
1	4	2.43	29.82	2.16	2.20	6.50	59.32
3	2 to 4	2.42	31.96	2.08	3.40	2.70	59.86
(MATRICES).							
6	4	2.38	32.14	2.64	3.70	2.00	59.52
9	2 to 3	2.38	31.90	1.56	4.20	5.30	57.14
4	2 to 4	2.36	32.00	1.64	3.60	2.00	60.76
2	4	2.35	32.50	0.68	4.00	5.50	56.72

There is no special arrangement in the above table. It merely serves the purpose of showing some of the more striking characteristics of various oölites and matrices.

All of the above samples, which were taken from the previous table, are arranged in order of their decreasing specific gravity. In this connection note the relation of hardness, H_2O, Fe_2O_3 and Al_2O_3. In other words there is, at the top of the list diaspore, and at the bottom, gibbsite, the intermediate members being mixtures of the two with doubtless some bauxite. It is interesting to note that, apparently, the matrices carry no diaspore, though they may be in intimate contact with strongly diasporitic oölites. It is also worthy of note that all oölites listed under Table I. whose hardness is greater that 4 have an average specific gravity of

2.7175, and all with a hardness of approximately 4 and under have an average specific gravity of 2.4166, while the average specific gravity of the matrices is only 2.3675.

TABLE III.

DESCRIPTION OF SAMPLES.

No. 19. Hard and porous granitic.
20. Dull reddish brown oölite.
21. Dull red to dark brown oölite.
22. Dull red oölite.
23. Very slightly vitreous brown oölite.
24. Brown and slightly vitreous oölite.
25. Dark brown vitreous oölite.
26. Black vitreous oölite.
27. Black vitreous oölite.
28. Black vitreous oölite.

In Table III. it will be noted that the physical description has been abbreviated considerably by simply stating the one characteristic of each sample that is likely to appeal strongest to the unaided eye.

It was my desire in selecting these samples to obtain gibbsite, bauxite and diaspore in their purest forms, together with a certain number of intermediate members. Great care was exercised in an endeavor not to have more than two hydrates in a single sample. The samples are quoted throughout in order of their decreasing water content, so that on the extreme left (in Table IV.), gibbsite is on the right, diaspore. However as we will note later the rise is bauxitic or diasporitic conditions is not necessarily proportional to the total loss on ignition.

TABLE IV.

CHEMICAL ANALYSES.

	19.	20	21	22	23	24	25	26	27	28
H_2O.....	32.74	30.54	29.54	27.97	26.97	24.03	21.62	18.76	17.50	14.89
SiO_2.....	2.30	2.16	2.63	2.48	3.56	2.50	3.68	3.28	2.96	2.00
TiO_2.....	2.70	1.30	2.60	5.60	1.40	1.30	1.20	1.40	0.70	0.40
Fe_2O_3.....	2.40	6.00	2.80	10.70	4.70	8.50	7.30	8.40	9.50	10.00
Al_2O_3.....	59.86	60.00	62.44	53.25	63.37	63.67	66.20	68.16	69.34	72.71

Without entering into a detailed description of these results, it will suffice to say that all samples are obviously low in silica, and, as a general proposition, the titanium becomes lower and the iron higher as the oölites become of lower hydrate. No. 22 is to be noted as a special exception.

TABLE V.

MINERALOGICAL CALCULATIONS WITHOUT DIFFERENTIATION.

	19	20	21
Gibbsite	88.60	89.00	92.20
Kaolinite	4.90	4.60	5.60
Ilmenite	4.05	1.95	3.90
Limonite	1.20	6.25	1.70
Totals	98.75	101.80	103.40

	22	23	24	25
Bauxite	69.20	81.60	83.25	85.40
Kaolinite	5.35	7.60	5.40	7.90
Ilmenite	8.40	2.10	1.95	1.80
Limonite	9.20	4.70	9.10	7.80
Totals	92.15	96.00	99.70	102.90

	26	27	28
Diaspore	76.90	78.70	83.65
Kaolinite	7.15	6.40	4.30
Ilmenite	2.00	1.05	0.60
Limonite	9.10	10.65	11.45
Totals	95.15	96.80	100.00

The aluminum hydrate calculations in Table V. are purely empirical. From a casual glance at the chemical analyses, we should be led to believe that in the first three listed, gibbsite predominated as hydrate, while in the next four, bauxite was the dominant member. In the last three samples we should naturally expect to find diaspore as chief constituent. Consequently for those samples in which there is a double hydrate, we do not and should not get a total of 100 per cent. without differentiation.

Theoretically, at least, those cases with a total of less than 100 per cent. have an excess of combined water for the compounds

assumed; whereas in cases of more than 100 per cent. there is a deficit of water which is due to the reckoning of too much aluminum hydrate.

As the writer feels reasonably assured that sample No. 19 contains no hydrate below the triple type and that No. 28 contains practically none above the mono. variety, why is it that we do not add to 100 per cent. in the former case? There are many explanations that might be offered, but the one that appears most plausible is the possibility of there being present even a higher hydrate than the triple, or gibbsite. In this connection is an interesting case of a rare occurrence of secondary gibbsite. Repeated analyses were made of this sample because of its unusual composition. As no satisfactory recasting could be made on the basis used it occurred to the writer that an explanation might lie in the fact of a slight admixture of higher hydrate.

Note the very high combined water content (1.80 per cent. higher than in gibbsite) and the low specific gravity.

SECONDARY GIBBSITE.

(Chemical Composition.)		(Mineralogical Composition.)	
H_2O	36.40	Gibbsite	94.60
SiO_2	0.56		
TiO_2	None	Kaolinite	1.20
CaO and MgO	None		
Fe_2O_3	1.00	Ilmenite	None
Al_2O_3	62.04	Limonite	1.15
Totals	100.00		96.95

Specific gravity, 2.25.

The manner of arrangement is more scientific in this case than in Table V. In Table VI. are placed all samples that contain any gibbsite at all into a gibbsite-bauxite series and the remainder into a bauxite-diaspore series. It seems of special interest that sample No. 2 which is supposed to be chiefly bauxite (see Table V.) actually contains a relatively small amount of this mineral. Also in case of No. 24, in which the total water (see Table IV.) is roughly 2.00 per cent. below the theoretical for bauxite, there is a slight amount of gibbsite. In both samples the

TABLE VI.

DIFFERENTIATED MINERALOGICAL CALCULATIONS.

	19	20	21	22	23	24
Gibbsite	88.60	74.70	64.75	68.90	36.65	1.95
Bauxite	....	12.50	24.15	8.10	49.15	81.45
Kaolinite	4.90	4.60	5.60	5.35	7.60	5.40
Ilmenite	4.05	1.95	3.90	8.40	2.10	1.95
Limonite	1.20	6.25	1.70	9.20	5.70	9.10
Totals	98.75	100.00	100.10	99.95	100.20	99.85

	25	26	27	28
Bauxite	62.75	40.50	27.65	00.10
Diaspore	19.75	41.40	54.50	53.55
Kaolinite	7.90	7.15	6.40	4.30
Ilmenite	1.80	2.00	1.05	0.60
Limonite	7.80	9.10	10.65	11.45
Totals	100.00	100.15	100.25	100.00

explanation for the apparent discrepancy is to be found in the rôle played by the accessory components.

CONCLUSION.

From the foregoing may be concluded:

1. That the chief aluminium hydrates in the Arkansas bauxite field are gibbsite, bauxite and diaspore.

2. That gibbsite is present in all types of ore, while bauxite and diaspore are confined to certain of the oölites.

3. That bauxite and diaspore are subsequent to the gibbsite, having resulted from it because of more stable conditions attending the lower hydrates.

N. H. WINCHELL AND THE AMERICAN GEOLOGIST.

By H. Foster Bain.

The chapter entitled "The State of England in 1865" is one of the few that makes a lasting impression on the readers of Macauley's "History of England." Such general reviews serve so useful a purpose that little other excuse is necessary as an introduction to the brief paper which follows on the state of geology in America in 1888 and the part which was played in the subsequent development of the science by N. H. Winchell and the *American Geologist*. If other excuse be sought let it be found in the wisdom of that pause which enables us to gain in brief retrospect an estimate of the progress of geology in the intervening years, and a more just appreciation than time usually allows of the greater difficulties which beset the earlier steps of scientific progress.

In America, geology has received support from three main sources. First, in point of time and probably in number of workers, the schools; second, the surveys, and third, the mining companies. In 1888 two at least of the universities that are now the most vigorous and influential supports of geology were still unfounded, and many, almost beyond enumeration, that now maintain large and well-equipped faculties in geology, then either gave no instruction in that science or relegated it to a subordinate place in a general department of natural science. Speaking broadly, there was no place in America where a student could go for systematic graduate instruction in geology as distinguished from undergraduate work or mere prolongation of undergraduate courses. The teachers of the present generations were then still largely students in the German and other foreign universities. It is true that as early as 1885 G. H. Williams had begun his work at Johns Hopkins only as instructor in mineralogy and in the department of chemistry. The trustees of that institution, it is said, twice

solemnly resolved not to establish a department of geology—only to be forced in the end to care for one which grew up in spite of solemn resolutions because of the needs of a fast-growing country. At Harvard, Yale, Michigan, and other universities, and at the Columbia and Michigan Schools of Mines, geology was indeed being taught. It needs, however, but a brief study of the program of courses of that period to make clear that it was still as a non-professional subject. Purposeful training of geologists lay still in the future not only in the United States but in Canada. Professor Winchell and those who joined him in founding the *American Geologist* were men who had learned the methods of geology in the field rather than the laboratory; and the day when men might begin work trained to it, was just beginning.

In 1888 Stanford University had not come into being. Jordan was still president at Indiana with Branner as professor of geology, though for the time on leave and busy with the Arkansas survey of which more anon. At Berkeley "Professor Joe" was still teaching the philosophy of life, and a very good one it was, to men and women influenced by him to right thinking and living, rather than to measuring dips and angles. Lawson, a young graduate, was working on the Canadian survey and had not yet come to infuse with his virile personality the study of geology on the coast. In the Middle West, Calvin, the much-loved, was at Iowa; N. H. Winchell at Minnesota; Orton in Ohio; and Chamberlin but newly come to be president of Wisconsin University. In his faculty Van Hise was professor of geology, but that nearly told the tale for instruction was to undergraduates and not greatly specialized. It was not until 1891 that Chamberlin brought Salisbury from Beloit and the two, with Van Hise and Hobbs, organized a well-rounded department for professional instruction in geology. The University of Chicago, in 1888, was only a dream in the minds of a few far-seeing men and it was not until 1892 that the geological department which, after developing a coördinate department of geography, has just moved into a beautiful and fitting hall that is to be its home, was organized. In the east, Shaler's delightful lectures were attracting crowds of undergraduates to Harvard, where, too, Davis was beginning the

river studies that contributed so greatly to the development of the now familiar science of physiography. At Yale J. D. Dana was still active, though old. At Columbia "Uncle" John Newberry (someway they run to Uncles at Columbia) was lecturing to wily young engineers who knew all too well the art of diverting questions. Kemp was a young instructor at Cornell; Lindgren was a minor assistant on geological survey in California; Ransome, Leith, Spurr, Brooks, Irving, George Otis Smith, Daly, Brock—all these, and they are only a few of the many who might be mentioned—were still school boys.

Among the survey conditions were also strikingly different from those now obtaining. Speaking broadly, the early impulse toward state and government activity in geological work had largely exhausted itself, while the later one of today had but begun. In the East, New York, the pioneer organization, maintained a small staff which, under direction of James Hall, was busy working out and publishing paleontological results of large scientific interest but little likely to arouse enthusiasm among legislators. In Pennsylvania the second survey had largely completed its field work and was deluging the public with the numerous small black volumes of material too little digested, which a generous printing appropriation encouraged. Maryland, Virginia, West Virginia, Tennessee, and indeed most of the eastern and southern states, were doing nothing. In North Carolina, however, Holmes, then a modest state geologist, was getting out an occasional small bulletin and in Alabama E. A. Smith was making the best of a very small appropriation. In the Middle West Orton was summarizing results, Indiana was hopelessly in politics, Minnesota was content with a thin annual volume and an occasional thinner bulletin. In general the surveys, such as existed, were but half-heartedly supported and were devoting their energies to severely scientific studies that made little popular appeal. Almost alone in Arkansas was the new set toward economic geology to be observed. There, in a most unpromising environment, so far as superficial observation indicated, Branner had brought together a strong corps and was justifying the expenditure of public funds on a geological survey as a means of develop-

ment of a state. With Winslow, Penrose, Newsome, Drake, Perdue, J. F. Williams, and others of like calibre, careful systematic work of permanent value to the commonwealth was being done. Of even more significance, an example was being set and men were being trained. The Missouri Survey, conducted by Winslow, was a direct lineal descendant of that of Arkansas, and Keyes came from the Missouri staff to found that of Iowa. In other states, if the influence of Branner and his work was less directly traceable, it was none the less powerful; but at the time Arkansas stood almost alone in the prominence it gave to the class of work that is now common.

In 1888 the United States Geological Survey was a very different organization from the splendidly staffed and munificently supported institution of the present. The appropriation for the year 1888 was $635,240, as contrasted with the $1,620,520 voted to the survey by the Congress which has just adjourned. This increase in funds has made possible, as it also measures, public approval of various changes of method and enlargements of scope. At the time of which I write, J. W. Powell was director, though his attention was, for the time being, diverted to other matters than geology. The Bureau of Ethnology, the first of the great bureaus that have grown up as offshoots from the survey, was also under his charge and a beginning was being made on the hydrographic work which eventually formed a basis for the Reclamation Service. The Tenth Annual Report of the Survey, being that for the year ending June 30, 1889, was the first to appear in more than one volume. It is perhaps significant that the second part was devoted to studies of the arid lands. It was only much later, after the Indians, the waters, and the forests had received due attention, that a start was made on a Technological Division of the Survey, which became in time the Bureau of Mines. In 1888 the prime interest at Washington, as throughout the country, was not in the economic phases of geology. W J McGee, that erratic but forceful self-taught geologist from the prairie, was dominant in the organization and McGee, neither by training nor experience was equipped to appreciate the needs of the mining communities as regards geology. Perhaps it was just

as well, since methods were still largely to be developed and there remained to be done much preliminary work in stratigraphy, paleontology, and petrography. Cross was about to begin applying the microscope to the study of the rocks of San Juan and Iddings was at work in Yellowstone Park. The "Petrographical trust" had not been formed and petrographers were too busy learning to recognize rocks to worry greatly over their origin or classification. Emmons and Becker, almost alone, worked to maintain the King tradition at Washington but the set of the current was strong against them. It is worth recalling that when Clarence King became the first director of the Geological Survey, he proposed to extend its activities over the whole of the United States and planned a group of division organizations, each modeled after the Fortieth Parallel Survey which he had so successfully conducted. Failing to secure funds or definite approval for this plan, he resigned. Powell, who succeeded him, was an opportunist and extended the scope and field of the survey as the way opened, rather than according to any definite plan. Under him the survey was in 1888 fast becoming a great national scientific bureau with no determined limits to its field and a strong indisposition to recognize the existence or utility of any such. This provoked suspicion and aroused opposition outside Washington and was one of the factors that lead to the founding of the *American Geologist*. It is fair to say that at the time in Washington, as at the State capitols, and in the universities, geologists were drifting rather than working along pre-agreed plans. Work everywhere was most imperfectly coördinated and, in particular, there was, as compared with the present, little serious attempt to make geology immediately useful. Like German philosophy of the period a little before, it was mainly in the clouds.

Few mining companies in 1888 employed geologists even occasionally. The need of specialists was not felt and such problems of exploration, development, or litigation as arose were passed over to the mining engineer who was expected to remember from lectures heard in his freshman year, enough to solve the problem in hand. Exploration, in general, was simple since outcropping orebodies were still to be found. Systematic under-

ground mapping of foundations as an aid to development was virtually unknown. It was only in 1900 the work was organized at Butte. D. W. Brunton's paper read before the American Institute of Mining Engineers in 1906 was responsible for the initiation of similar systematic work at many mines throughout the west. Long before 1888, S. F. Emmons at Leadville had demonstrated to the miners the importance of a correct knowledge of stratigraphy in following orebodies, and in the anthracite fields geological information was fully appreciated. To a less extent coal and iron mining companies depended on geologists, while I. C. White and Edward Orton were still busy proving to oil and gas men that empirical methods were capable of improvement. A few of the great railroad companies employed geologists, though in minor capacities. The Northern Transcontinental Survey, organized by Pumpelly for the Northern Pacific, had come to grief in 1884, and nowhere was there an organization comparable to the highly efficient staff now employed by the Southern Pacific. The need for such work had not yet made itself felt and while, as had been true since J. D. Whitney proved it could be done, capable men were making their living as consulting geologists, their numbers were few and their fees small. The big companies of the present day had not been organized. There was no American Smelting & Refining Co., no. U. S. Steel Corporation, no Amalgamated Copper Co.; the Standard stood almost alone among big oil companies, and nowhere was there the field for specialization in technical staffs, that exist today. Cripple Creek, Goldfield, nor the Klondike had been discovered and Alaska was a far country only to be explored by venturesome young men, such as Willard Hayes, when properly chaperoned by the military arm of the government. Farrel had not come back from Central Africa with stories of Katanga, and the Rand had not poured out its millions. Silver was dominant and learned treatises were written by learned geologists to prove that it must continue so since there was not enough gold to conduct the world's commerce. In the United States the Lake Superior mines were dominant in copper, and the prospectus of a porphyry mine would have been considered the work of a Jules Verne or a Baron Munchausen. The Mesabi

range had not been discovered; the Alabama iron mines were but beginning to be appreciated; cargoes of Swedish magnetite had not begun to cross the Atlantic, and it was still believed that all good Portland cement must be imported. In 1888 the total coal production of the United States was 148,659,657 tons. In 1914 it was 570,840,000 and the difference translated into steam and so to useful work, reflects the progress of the intervening years.

It was into a field where geology was so little appreciated and so poorly supported that the *American Geologist* came. Its coming was neither an accident nor the result of sudden caprice. For several years, beginning in 1881, a small group headed by Alexander and N. H. Winchell made persistent efforts to organize geological work in America along broader lines and to secure some general medium for publication of geological results. At the time there was no journal devoted to the science in North America, and no foreign journal which had a general circulation. The *American Journal of Science* had already begun to specialize in physics and mineralogy, although in the volume closed in December, 1887, there were twenty papers published that were geological in character, five being by western men. That so large a number found place despite the pressure for space, sufficiently indicates the genuine and widespread interest in the science. The *American Naturalist,* under the guidance of Cope, emphasized the morphological rather than stratigraphical phases of paleontology so far as it entered the field at all. The projectors of the new enterprise had at first hoped that the American Association for the Advancement of Science could be enlisted to support a geological journal but in 1888, despairing of outside support, determined to venture alone. It was felt that geology needed an organ of its own and that the geologists could be relied upon to support an independent and well-conducted journal. It was at Minneapolis in the study of N. H. Winchell that the decision to undertake the responsibility was reached, and from the first to the last, N. H. Winchell was the dominant personality of the enterprise. The first editorial board was a notable one. It included Samuel Calvin, of the State University of Iowa, Edward W. Claypool, of Buchtel College in Ohio, Persifor Frazer of Phila-

delphia, Lewis E. Hicks of the University of Nebraska, Edward O. Ulrich, of the Geological Survey of Illinois, Alexander Winchell, of the University of Michigan, N. H. Winchell of the University and Geological Survey of Minnesota. It will be noted that all of the members of the board were men whose work had lain mainly in general geology; they were men of wide experience and broad sympathy rather than specialists. Geographically they were widely distributed but mainly from the Middle West, and through all the years of its life the *American Geologist* was a Middle West product, so far as a scientific journal can be said to be regional in character. Finally, none of the original editors were members of the United States Geological Survey or affiliated with any of the great government bureaus at Washington. It was inevitable that the *Geologist* should at once become the organ of the opposition, an attitude frankly expressed in the first number and maintained as occasion demanded, until with the changes of years the need for such opposition passed. There were times when the criticism the *Geologist* leveled at the Geological Survey was annoying and felt at Washington to be misdirected; but, remembering the times and the indefinite opportunist policy then followed on F. Street, who shall deny to the *Geologist* its share in the making of the today?

The general purpose and the projected scope of the *Geologist* was stated in the opening number, January, 1888, to be to constitute itself a reservoir of knowledge for those interested in current development of geology and related sciences. It was felt that "more than all, a thoroughly non-partisan publication is needed which shall be open to the properly worded opinions of all from the most powerful to the most obscure, and which is distinctively committed to no theory either of construction or obstruction." And further, "Many have had serious misgiving as to the result of the influence of the national geological survey in extending its operations into the settled states of the Union, and especially into states in which official geological surveys are in progress, fearing that by the concentration of all authority and control at the national capital, and by the extensive accumulation at one center of all the material illustrating the state and local geology of the

country, the local interest and effort may die out, and that ultimately the weight of public sentiment favorable to geological investigation may suffer diminution."

The first article in the first number was by Persifor Frazer and was on "A Short History of the Origin and Acts of the International Congress of Geologists and of the American Committee Delegates to it." It will be recalled that the American Association, itself organized mainly by geologists, had been the agent which called attention to the need of an International Congress of Geologists, and a powerful help in bringing about its organization. The American Committee was in fact selected by the American Association, which fact provoked some heart burnings as it was felt by some that an organization less miscellaneous in character and membership could more fittingly represent professional geologists in North America. The early numbers of the *Geologist* contained many papers and editorials bearing on this subject. Within the first year, September, 1888, the report of the American committee was published in full. It occupied 168 pages and was a first attempt to correlate American geology through coöperation of members of a large committee. The "correlation essays" of the United States Geological Survey came later.

Returning to the first number of the *Geologist,* other articles that appeared in it may be mentioned: N. H. Winchell wrote on "The Animike black Slates and Quartzites and the Ogishke Conglomerate of Minnesota, the Equivalent of the 'Original Huronian'"; Alexander Winchell discussed "The Unconformities in the Animike in Minnesota"; Calvin had two papers, "A New Species and New Genus of Tubicolar Annelida,' and "Notes on the Formations Passed Through in Boring the Deep Well at Washington, Iowa"; Claypool in "The Future of Natural Gas" furnished one of the first conservation papers printed in the journal. There was a strong editorial, written but not signed by Alexander Winchell, on "Geology in the Educational Struggle for Existence," protesting against the principle that "those departments are to be most fostered which bring most revenue to the college or university, and are held in highest popular esteem" —a protest that might profitably be reiterated from time to time.

A second editorial discussed the views of Irving and Chamberlin on the Lake Superior sandstones, and set the style for a series of long leaders that were really critical studies; a feature that characterized the *Geologist* in its early years. Later the current fashion of brief paragraphs or complete evasion of editorial responsibility now so common came to be followed in this as in other journals. At first at least, however, the editors took themselves and their task with a deal of seriousness, and real editorials, and real criticism were furnished. In the first as in all later numbers the journal closed with a summary of recent literature and brief personal and scientific notes.

It would be impossible to review in detail any considerable number of issues of the *Geologist*. The quotations and titles given illustrate fairly well the character and scope of the papers printed. The "Taconic question" raged through many volumes, there was always a strong emphasis upon geology as a means of culture and on the educational value of the science; much interest was taken in public affairs, and a helping hand was extended in many directions. From the first, Canadians as well as citizens of the United States were active in writing and the journal undoubtedly contributed greatly toward that fortunate unity that has characterized the development of geology in North America. Probably no feature of the *Geologist* was more striking than the fidelity with which it held to the announced purpose of welcoming contributions from even the most humble contributors, and many a local observer first saw his name in print in its pages. Much of this material had small value, but the encouragement given to men who became worth while was certainly sufficient justification. Another notable feature was the series of biographies which were printed. They were informing, scholarly, and usually good literature aside from the interest in the subject. Some of them were signed, as Cope's sketch of Hayden and Chamberlin's of R. D. Irving, but many were not and probably came in the main from the pen of N. H. Winchell, who in fact inspired the whole series. Not only men who had but recently died were the subjects of papers but early pioneers whose careers were fast becoming traditional were charmingly sketched. These biographies were illus-

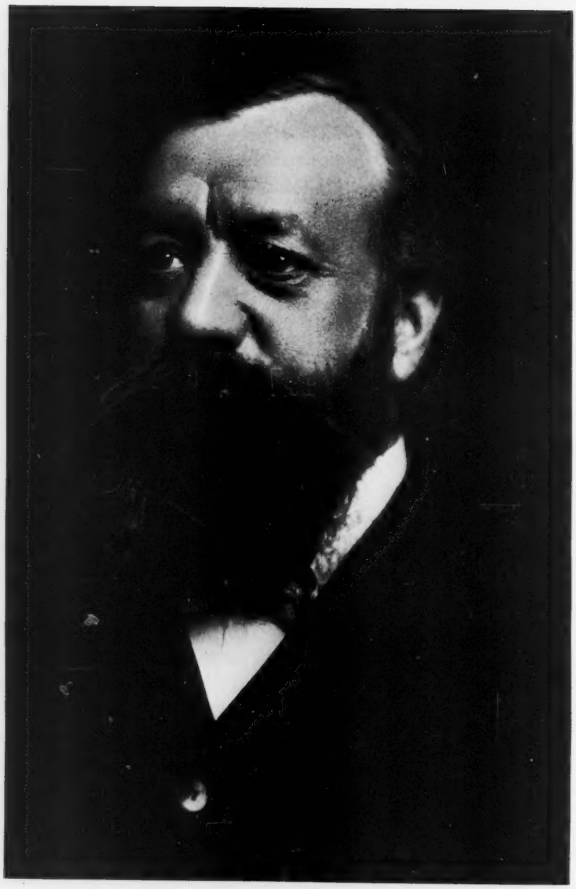
trated by portraits all the more notable in that the *Geologist* came before the days of halftones and the editor had carefully to balance the cost of each illustration against its probable value to readers.

In the conduct of the *Geologist* an attempt was at first made to hold each editor in turn responsible for one number. The plan never worked well, and the larger responsibility always rested upon Professor Winchell at Minneapolis, aided as he was much of the time by Mrs. Winchell and Warren Upham. During his year's absence in France in 1895, U. S. Grant conducted the journal. The board of editors changed somewhat from time to time but the last number, printed in December, 1905, bore the names of N. H. Winchell, Samuel Calvin, and E. W. Claypool of the original board. Others who served for longer or shorter periods were: John Eyerman, Robert Hay, C. L. Herrick, Arthur Lakes, A. C. Lawson, I. C. White, F. W. Cragin, Robert T. Hill, R. D. Salisbury, J. B. Tyrrell, F. H. Knowlton, John M. Clarke, C. E. Beecher, Warren Upham, M. E. Wadsworth, H. L. Fairchild, G. P. Merrill, H. V. Winchell, C. S. Prosser and O. P. Hay. It may be noted in passing that the editors gave not only their time and labor but money, since the *Geologist* for many years ran at a loss and there was an annual assessment to make up the deficit. Fortunately this was not always true and when it was consolidated with ECONOMIC GEOLOGY in 1906, it was an even keel. The consolidation was brought about, through the generosity of H. V. Winchell, by a desire to help solve the problems of those geologists who must count carefully the number of their subscriptions to professional periodicals, and the wish of the editors to devote their major time to other work. They felt, and in large degree justly, that the particular things for which the *Geologist* had striven, had been largely brought about.

In 1906, geology in America was in a very different position from that it occupied in 1888. In the schools it was recognized not only as an excellent medium of instruction and undergraduate training, but large departments in many universities and mining schools used it in training men for professional work. The economic geologist had arrived and was a recognized factor in

development of industry and enterprise throughout the land. Most of all, avenues had been opened and means found for ensuring correlation of studies and coöperation of work among geologists. The International Congress of Geologists had virtually completed its first great activity, the establishment of an international scheme for geological mapping, and was about to enter upon the second, the world wide study of great single resources such as coal and iron. The Geological Society of America, established in the autumn of 1888 following a call in the *American Geologist* of June of that year, was an honored and flourishing institution. The American Association for the Advancement of Science had in 1901 adopted the suggestion made in early pages of the *Geologist* and abandoned the annual volume for the weekly, *Science,* so that there was a medium for prompt exchange of scientific news. The *Journal of Geology,* printed at the University of Chicago, had grown up as a specialized organ devoted particularly to the philosophical and non-economic phases of the science. Numerous journals pedagogical or semi-pedagogical in character gave adequate space to the biographic phases of the subject, and ECONOMIC GEOLOGY had come to serve those interested especially in the applications of the science.

The *American Geologist* was not crowded out; there would be ample material to fill its pages today, but it and its editors had earned the right to retire with a feeling of substantial accomplishment. Its old readers and many friends echo heartily and honestly the modest words of its closing editorial, that the editors "are sure that on the whole the influence of the published volumes has been wholesome." They have been more than that; the influence of the movement during eighteen growing years was to solidify and to coördinate geology in America, and throughout this period the guiding spirit, tireless co-laborer and generous friend of all sincere students of science was he under whose editorship the volumes were published from first to last.



N. H. Winchell

THE WORK OF N. H. WINCHELL IN GLACIAL GEOLOGY AND ARCHÆOLOGY.

WARREN UPHAM.

For a period of forty-five years, from 1869 until his death, N. H. Winchell was deeply interested in glacial geology and devoted a portion of his time to its study. Aided by a thorough familiarity with the literature, his field observations and the thoughtful reflection of his keenly analytical mind found expression in not a few papers of more than passing interest. His many detailed observations and discoveries relating to the conditions of formation of the drift deposits and the sequence of events in the Ice Age were interpreted with a clearness and logic that have rendered them a substantial contribution to our general knowledge of the glacial period.

In archæology Winchell's first writings were of the Indian mounds. His earliest contributions appeared in the Fifth Annual Report of the Minnesota geological and natural history survey for the year 1876, being descriptions of the earthworks in Houston and Hennepin counties.

"Primitive Man at Little Falls," and additional notes of stone implements in other parts of Minnesota, are the theme of ten pages in the Sixth Annual Report for 1877, with a plate of figures of several of the chert and white quartz implements found in the upper part of the valley drift of the Mississippi river at and near Little Falls in the central part of Minnesota. From that date, through thirty-seven years, N. H. Winchell was continuously interested in the evidences of man's presence in America during the late part of the Ice Age.

Winchell's main contributions along the lines stated may best be considered in chronological order.

In 1873 his description and discussion of "The Drift Deposits

of the Northwest"[1] appeared. It contains an admirable word picture of the border of the waning ice sheet, when thinned by ablation and overspread by the drift that had previously been borne along in the basal part of the continental glacier. That this description was almost prophetic of the drift-covered and forest clad borders of the Malaspina glacier or Piedmont ice-sheet between Mt. St. Elias and the ocean, which was later to be explored and described by Russell[2] in 1891 and 1892, will appear from the following quotation from the view written nearly twenty years earlier than Russell's actual observations.

"In regions far to the north, the eye probably would not be able to discern any object except that of the universal ice. The surface of the ground would be thousands of feet below the traveller, if we may be permitted to presume so hardy a human being. Like Dr. Kane exploring the great Humboldt Glacier of Greenland, he would meet with countless obstacles and dangers. But those obstacles would consist of hummocky ice, or crevassed ice, or perpendicular icewalls. He would see no soil, no rocks, no vegetation, no animal life. The winds would whistle, storms would rage, snow would be drifted about, and the ineffectual sun would rarely venture to smile on the dreary waste. Farther to the south the explorer would find isolated spots of bare ground. He would see about them the accumulated débris of bowlders, gravel and dust, from constant winds, spread more or less over the ice-field, staining its painful whiteness, and showing the more grateful aspect of earth and stones. Another hundred miles farther south, and he finds the evidence of the dissolution of the ice-sheet multiplying. Occasional streams of water run on the surface of the ice, or plunge into some of its openings. Deep gorges reveal multitudes of fragments of rock frozen into the ice, and occasional bands of dirt and gravel embraced in the solid ice. The surface is everywhere dirty, or perhaps muddy from the wasting away of the surface of the glacier. He meets frequent openings, in which generally water may be seen or heard. Into these gorges the debris slides down the sloping sides, increasing the insecurity of his footsteps. Still farther south the general surface is covered with a pulpy earth, mingled with stones and bowlders. The ice is evidently much attenuated. The areas of firm uncovered terra firma are wonderfully increased in size

[1] *Popular Science Monthly*, Vol. III., pp., 202–210 and 286–297, June and July, 1873.

[2] *National Geographic Magazine*. Vol. III., 1891, pp. 53–203 with 19 plates and maps. *Am. Jour. Sci.*, third series, Vol. XLIII., pp. 169–182, with map, March, 1892. *Am. Geologist*, Vol. VIII., p. 384, December, 1891.

and frequency. The ice itself is crowded into the valleys, or, if it be in a broad, level tract, like the State of Minnesota, the surface is covered with the débris of the conflict of ice with earth, the ice itself being visible only in those places where crevasses reveal it, or where deep gorges are worn by running streams. Travelling still farther south the explorer would come upon large areas in which he would not be able to know whether the glacier underlay the superficial drift or not. If he were to stop on one of those wide areas and make his latitude and longitude certain, by a series of astronomical observations, he might find to his surprise, after a few years' residence, that his observatory and apparatus had been bodily carried by an imperceptible motion some rods to the south. If he were to penetrate the earth on which his foothold seems so steadfast he might find, equally to his surprise, that he was still riding on the surface of a vast ice-sheet, the earth and soil of which may have furnished him annual crops of potatoes and barley. In other places in the same latitude he would find the ice laid bare over considerable areas, washed clean by the drainage incident to the dissolution of the glacier. The turbid streams would be vastly larger than those which occupy the same beds today. They would run with tenfold more violence. The drift materials would be freed from the clayey portions, and be spread along their channels in curious and varied assortment. In some places the thickness of the whole sheet of drift would be brought under this washing and stratifying process. In others the ice gently dies out, and lets it down on the rocky surface without any change from the condition in which it lay on the glacier."[3]

This view of the large amount of englacial drift, made finally superglacial by the melting of the ice-sheet, was stated less fully also in the same year on page 62 of the first Annual Report of the Minnesota Survey. During the progress of this survey the writer found in observations on Lakes Benton, Shaokatan, and Hendricks, evidence that in southwestern Minnesota, near the crest of the Coteau des Prairies, the depth of the englacial drift there deposited as the upper part of the drift sheet was at least 40 feet.[4]

Twenty-five years later my special study of "Bird's Hill, an Esker near Winnipeg, Manitoba," in the central part of the basin of the glacial Lake Agassiz, has shown that the englacial drift on that nearly flat or in part undulating and moderately hilly broad interior region of our continental ice-sheet amounted to some 40 or

[3] *Popular Science Monthly*, Vol. III., pp. 293, 294.

[4] "Geology of Minnesota," Vol. I, 1884, pp. 603-604. Compare also in the same volume, pp. 387, 440, 480, 668.

50 feet in thickness when deposited, comprising the greater part of the glacial and modified drift. Moreover, the thickness of the basal part of the ice into which abundant englacial drift had been carried in the region of Bird's Hill was much more than 500 feet, being probably 1,000 or even 1,500 feet, the ice-sheet there having doubtless attained at the maximum stage of the snow and ice accumulation a depth of a mile or more.[5]

What seemed to me on the first reading to be a very unlikely and fantastic theory in the above quotation from Professor Winchell published in 1873, was indeed practically duplicated by Russell in actual discovery less than twenty years afterward, and has been practically proved for our ancient North American ice-sheet by my own field work and studies. It should also be remarked that the conditions of drift transportation and deposition so long ago clearly portrayed by Winchell deserve more general and clear recognition than has been accorded by many glacialists.

From the early masters and pioneers of American geology, as Edward Hitchcock, James D. Dana, Sir William Dawson, James Hall, his own brother, Alexander Winchell, and John S. Newberry, with whom he was an assistant on the Ohio survey, Newton H. Winchell received the education and inspiration for his life work. In Ohio he had surveyed and mapped recessional moraines of the waning ice-sheet and the beach ridges of the glacial lake later named, in its successive stages, as Lakes Maumee, Whittlesey, and Warren, which covered the northern edge of Ohio as the precursor of the present diminished Lake Erie. At the beginning, therefore, of his work in Minnesota, his first report contained on page 63, the first reference of the ancient lake in the Red River valley, since named Lake Agassiz, with its channel of outflow southward at Brown's valley, to confinement on the north by the barrier of the receding continental glacier.

In pages 197–209 of the fifth Minnesota report for 1876, with maps, published in 1877, Winchell presented the description and discussion of origin of the Mississippi river gorge from Fort Snelling to the Falls of St. Anthony. This description has more than usual value since it furnishes a clue to the actual duration in

[5] *Bulletin G. S. A.*, Vol. 21, pp. 407–432, with a map and sections, July, 1910.

years of postglacial time. The gorge is attributed by Winchell wholly to postglacial erosion. The earlier interglacial course of the river is mapped by way of the valley of Bassett's creek and by the series of lakes in the west part of Minneapolis, namely Cedar Lake, the Lake of the Isles, and Lakes Calhoun and Harriet. Thence it trends southeast and south to the broad valley of the Minnesota river.

Dividing the length of the postglacial gorge, about eight miles, by the annual rates of recession of the falls, since their earliest observation and record by Hennepin in 1680, the duration of postglacial time is estimated between 7,000 and 8,000 years.

Probably this time measurement of a part of the geologic record, affording a proportional means for arriving at an estimation of the age of the earth, may be rightly regarded as Winchell's greatest service to glacial geology. It was partly rewritten and more fully published by the Geological Society of London, in its *Quarterly Journal* of November, 1878 (vol. XXXIV., pp. 886–901); and ten years later in the second volume of the Final Report of the Minnesota survey it was republished in great detail (pp. 313–341 with four maps and eleven plate views from paintings, sketches, and daguerreotypes). The average estimate, based on three computations, for the length of the postglacial period is 7,800 years.

Similar estimates have since been obtained for this period by Prof. G. F. Wright and the writer, from the similar consideration of the gorge of Niagara Falls. In Europe also closely accordant computations and measurements of the time since the departure of the ice-sheet from southern Sweden and Norway have been recently published by Dr. N. O. Holst and Baron DeGeer, indicating that the end of the Ice Age was nearly contemporaneous on the opposite sides of the North Atlantic ocean.

Another very important study by Winchell deals with the duration of the principal interglacial stage or interruption of glaciation in Minnesota, marked by retreat of the ice border at least so far as to uncover the south half of the state. The computation is based on the interglacial erosion by the Mississippi river in the course before mentioned, passing by Lakes Calhoun and

Harriet. The time estimated is about 15,000 years. This represents the interval between the melting away of the earlier ice there and a readvance of that ice-sheet, or an entirely new accumulation of continental ice, covering this area and extending in its maximum stage at least as far southward as Des Moines in central Iowa.[6]

The preglacial course of the Mississippi is shown by the map accompanying this paper as probably traceable from Rice creek, a few miles north of Minneapolis, southeastward by Lake Johanna and McCarron Lake, to join the present river valley at the mouth of Phalen creek in St. Paul. In the chapters on Hennepin and Ramsey counties in Volume II. of the Final Report of the state survey, published in 1888, the preglacial and interglacial courses of the Mississippi had been only very briefly noticed, without mapping, since attention was there directed almost wholly to the postglacial gorge.

The relationship of the Ice Age and the antiquity of man in America claimed Professor Winchell's increasing interest with much controversial investigation and authorship to the end of his life. Previous to the year 1893 numerous supposedly indubitable evidences of the contemporaneousness of man and the Glacial period on this continent had been steadily and calmly discovered and placed on record by many observers. Then came a sudden and severe storm of critical distrust and denial by a group of very prominent American scientists. The storm broke with its full force at the annual meeting of the American Association for the Advancement of Science in August, 1893, held in Madison, Wis. The volume of the *Proceedings,* A. A. A. S., for that meeting reports the papers read for and against the evidences of glacial man in America only by their titles and authors' names, without mention of the ensuing discussions; but both these papers and the discussions by many members are well summarized by the writer in a report on the "Pleistocene Papers at the Madison

[6] "An Approximate Interglacial Chronometer," *Am. Geologist,* Vol. X., pp. 69-80, with a map and sections, and p. 302, August and November, 1892.

Meetings," of the G. S. A. and A. A. A. S.[7] N. H. Winchell was not present at this meeting, for he was at that time busy with the field work of the Minnesota survey; but the discoveries of plentiful flaked fragments of white quartz in the upper beds of modified drift of the Mississippi at Little Falls, Minn., derived, as all observers believe, from the making of stone implements, formed one of the subjects of sharp and vehement debate.

A year earlier, in June, 1892, this locality had been visited by Wm. H. Holmes, who examined the gravel and sand plain and the included quartz flakes, in company with Winchell; and the adverse opinions of Holmes, denying the adequacy of the evidence of great antiquity of man there, had already been published.[8]

The most careful descriptions and investigation of this question as represented in Minnesota were published by Winchell in 1902, comprising 16 pages in a quarto. The conclusions of Winchell and Brower, reached after much field examination and long deliberation, ascribe the quartz flakes to men dwelling there in the time of the final melting of the ice-sheet on the more northern part of the Mississippi basin, while glacial floods yet poured along this valley.

The attention of American glacialists and archæologists was again drawn to this question by the discovery in February, 1902, of a human skeleton at the depth of 20 feet in a loess terrace of the Missouri river valley near Lansing, Kansas. It was found by Concannon brothers in excavating a tunnel and underground storehouse on their farm. Winchell and the writer visited this place, examined the loess section, and learned full details of the excavation and discovery. We were led by the ample evidence to refer the skeleton to the Iowan stage of the Glacial period, which I estimate to have been about 12,000 or 15,000 years ago.[9] Pro-

[7] *Am. Geologist,* Vol. XII., pp. 165–181 (see also pages 187–8), September, 1893.

[8] "Vestiges of Early Man in Minnesota," *Am. Geologist,* Vol. XI, pp. 219–240, with a map and sections, 1893.

[9] Warren Upham, "Man in the Ice Age at Lansing, Kansas, and Little Falls, Minnesota," *Am. Geologist,* Vol. XXX., pp. 135–150, with two plates from photographs (front and profile views of the Lansing skull, with the thigh

fessor T. C. Chamberlin, who visited the Concannon farm soon afterward, giving to the section a very careful investigation, came to a different interpretation of the loess deposit under which the skeleton was found, whereby he concluded that it was more probably of some later, but not exactly determinable age.[10]

During the last eight years of his life, from the spring of 1906, Winchell was in the service of the Minnesota Historical Society in charge of the Department of Archæology. In this work he was the successor of the late Hon. J. V. Brower, by whom several valuable archæological monographs had been published. The latter were based on very extensive collections of aboriginal implements, weapons, and ornaments, from Minnesota and other states west to the Rocky Mountains and south to Kansas. So far previously as in 1881, Winchell had come to be of the opinion which has since been generally adopted by archæologists and ethnologists, that the artificial mounds of the United States and Canada were not constructed by some distinct race of higher culture than the present American Indians as many had before supposed, but by the immediate ancestors of the present tribes. In a paper on the Ancient Copper Mines of Isle Royale, he had written as follows:

"It has been agreed for some years, by American geologists, that the ancient miners of Lake Superior were identical with the mysterious race known as the mound-builders. The evidence of this, first partially elucidated by Messrs. Squier and Davis, has multiplied by subsequent observations, so that there is now a concurrent series of facts pointing to that conclusion. It consists largely in the discovery of many copper implements in the mounds that have been opened. These implements contain small nuggets of metallic silver closely welded to the copper. At no other place in the United States are copper and silver thus naturally combined. They must have been pounded into shape, since the melting

bones), September, 1902. N. H Winchell, "The Lansing Skeleton," *Am. Geologist*, XXX., 189–194, September, 1902; and "The Pleistocene Geology of the Concannon Farm, near Lansing, Kansas," *Am. Geologist*, XXXI, 263–308, with three plates and three text figures, May, 1903. Presidential Address, Geological Society of America, December 30, 1902, "Was Man in America in the Glacial Period?" Bulletin G. S. A., Vol. 14, pp. 133–152.

[10] "The Geologic Relations of the Human Relics of Lansing, Kansas," *Journal of Geology*, Vol. X., pp. 745–779, October–November, 1902.

of the copper for casting would certainly have produced an alloy in which the appearance of the silver would be entirely lost. This, taken in connection with the well established mining methods of the Isle Royale miners, undeniably identifies them with the mound-builders.

"If we inquire further what relation the mound-builder bore to the aborigines found here by Columbus, we shall be compelled to admit from the evidence that the aborigines themselves were the mound-builders and the ancient miners."

It was now Professor Winchell's labor to extend, edit, and publish, for this Historical Society, the notes of the hundreds of groups of mounds in Minnesota which had been surveyed by Alfred J. Hill, Theodore H. Lewis, and Jacob V. Brower. On a conservative estimate this state has fully 10,000 Indian mounds, nearly all of which are described and mapped in the monumental quarto volume thus issued by Winchell in the year 1911, entitled "The Aborigines of Minnesota" (761 pages with 36 half tone page plates, 26 folded inserts and 642 figures in the text). This volume also comprises the description and history of the Indian tribes represented in the state from the earliest times, most notably the Dakotas and the Ojibways, their migrations, traditions, myths, habits of life and thought, customs, articles of manufacture, food, warfare, treaties, totems, pictographs, modes of burial, etc., in short a very detailed encyclopedia of these aboriginal people. It is of the same size and typography as the six volumes of the Final Report of the Geological Survey of Minnesota; and we may well affirm that Winchell merits the gratitude of Minnesota not less for this later work in archæology than for his earlier and larger work in geology.

His latest publication for the Minnesota Historical Society, printed in 1913, is entitled "The Weathering of Aboriginal Stone Artifacts, No. 1, a Consideration of the Paleoliths of Kansas," 186 pages with a map, 19 plates (views of stone implements from photographs) and 17 text figures, forming Part I. for Volume XVI., M. H. S. Collections. By varying degrees of patination on parts of the surface of stone implements which have been

[11] *Popular Science Monthly*, Vol. XIX., pp. 601–620, with eight text figures, September, 1881.

reshaped through chipping at widely separated times, Professor Winchell here gives reasons in support of his belief that paleolithic man in America antedated the very ancient Kansan stage of our continental glaciation.

In closing this brief review I wish to acknowledge the debt of gratitude which I owe to Winchell and the pleasure which my long association with him has given me.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

SHOULD A NEW DEGREE BE CREATED FOR PROFICIENCY IN GEOLOGY?

Sir: For ten years or more certain American geologists have added the title of "Mining Geologist" to their names when signing scientific articles appearing in public print. I have never heard any of them explain why they did so, but from the first time I saw it in print I have felt that in a way some such title, or degree, might be desirable.

We have a number of professional degrees outside of the old-time three professions, law, medicine and theology. Our industrial world makes such demands for well-trained men along many lines, particularly engineering, that a large number of men specially educated, devote their lives to meeting such demands; so we have civil engineers, mechanical engineers, mining engineers, etc., with proper academic degrees specifically referring to attainments of the holders. The granting of these degrees has become a matter of course with practically all our leading educational institutions, and we find about as high a degree of regularity in conditions leading up to them as we do in conditions leading to the older degrees, such as Bachelor of Arts, Master of Arts and Doctor of Philosophy.

It seems that the world in general recognizes the desirability of these degrees, and several others not named, and holders of

them, in a way, feel that each particular degree, partially at least, implies the attainments of the holder, as do the degrees of M.D. and D.D.

Customs like those above named are matters of growth, and come when there is a sufficient public demand for them. Perhaps no two educational institutions follow exactly the same requirements for granting any one of the degrees named, neither does such a degree carry with it the same weight when granted by different institutions, but neither the public nor our leading educators condemn the practice of granting them on that account.

Recently it has occurred to many educators, as well as to practical geologists, that the time would come sometime when the industries of the world would demand the services of well trained geologists in a manner analogous to its demand for the different kinds of engineers. In fact, it almost seems as though the time has already arrived. Wherever we turn we find a demand for geologists. The great public geologic surveys of practically all nations are well known. The ideal is being forced upon us day by day that for almost all kinds of great undertakings everything directly connected with the earth must rest upon geology as a foundation.

Thus we find the great English War Department sending one of the best English geologists with the army to the Gallipoli peninsula to direct the search for ground water for the army, and our own President Wilson naming a commission largely composed of geologists, with a geologist for chairman, to go to the Panama Canal to learn what kind of trouble it is there which has so largely baffled our best engineers.

The question, therefore, naturally arises whether or not it would be well to grant some kind of a title to express a certain proficiency in practical geology. As stated above, quite a number of good geologists personally have assumed such a title. This has been the outgrowth of an experience showing that they really felt the need of it. They are not engineers, so the degree of Engineer of Mines would not apply. Neither would any other degree in engineering exactly cover the want, or desire. Such

general degrees as Bachelor of Arts, Bachelor of Science, Master of Arts and Doctor of Philosophy are lacking in detailed expression, or intimation. They cover an exceedingly wide scope, and therefore are not explicit. The degree of Doctor of Philosophy may imply a profound and detailed knowledge of a Greek root, of a sensory nerve, of a mathematical abstraction, or of an indescribable philosophy as well as a high degree of proficiency along any branch of geology.

Early in last November I addressed a circular letter to about forty American geologists, asking the question, whether or not the time had come for our American universities and colleges to recognize a general public demand for some kind of degree expressing proficiency in general economic geology. To this date, December 14, answers have been received from about half the number. These answers are interesting, and at a proper time may be summarized and published. Suffice it now to say that more than three fourths of them favor granting some kind of a degree for the purpose named.

In the circular letter the thought was expressed that such a degree, if granted, should rank somewhere between the Master's degree and a Doctor of Philosophy. For a long time this last has been the signification of the highest scholastic attainment and presumably no one desires to endeavor either to replace it or surpass it. A new degree, therefore, should be below the Ph.D. Geology is such a broad subject, and rests directly upon so many of the fundamental sciences, *i. e.*, chemistry, physics, biology and mathematics, that the greater part of a four years' course in a good college or university should be devoted to them preparatory to a course in geology. Therefore, the new degree should be higher than the Bachelor degree.

It was suggested in the circular that it might be granted to a student who had completed from fifteen to twenty-five hours in mineralogy and geology in undergraduate work, and two full years of graduate work in geology in a good University. I would like here to expand this thought a little more, and invite all interested to take part in a full and free discussion of the whole

subject in all its aspects. It is my belief that should the proper time arrive some such a degree will be given. If the public—those interested—want the degree they will have it. If, on the other hand, the question does not develop into a general desire on the part of those interested, then it should not be given, and the few institutions who may actually grant it gradually will abandon it on account of there being no applicants. This is a sort of fatalistic view, but, after all, it is in keeping with practically all our customs. They come and go we know not why, but always at the behest of public desire.

I can report that out here in the middle west many young men now want the degree. There is now the greatest demand for well-trained geologists I have ever known, and young men are anxious to prepare themselves for meeting the demands of the times. Here, it is largely due to activities in petroleum mining in the mid-continental oil field and water mining on the great plains. Such men do not take courses in mining engineering, because they cannot get enough geology. Consequently they do not want the degree of Mining Engineer nor of any other kind of engineer. They want practical geology based upon a broad foundation and a degree that is expressive of their attainments.

Speaking entirely for myself I must say that as best I can read the public desire the time has come when educational institutions might feel safe in giving the degree spoken of without fear of a lack of public appreciation. There is no indication that we will lessen our application of geology in our great industrial life, and until then the degree will be sought by earnest young men, and appreciated by employers of geologists if it is not obtained too easily.

It is especially desirable that we make the requirements for the degree as nearly uniform as possible, although, of course, absolute uniformity is impossible. But that is no argument against the degree, nor against an attempt for uniformity.

ERASMUS HAWORTH.

UNIVERSITY OF KANSAS,
LAWRENCE, KANSAS.

Sir: In your letter of February second you raise an important question, which I think cannot easily be answered. It is undoubtedly true that the designation "Mining Geologist" is greatly abused, in being employed by many men who lack a technical training, which would properly fit them for the work; but would the granting of a degree in mining geology remedy the evil? The following considerations seem to me to be pertinent:

1. Abuse of the degree of "engineer of mines" is by no means uncommon, and the granting of this degree certainly does not prevent charlatanism, though it may check or reduce it to some extent.

2. There is a growing feeling in some quarters that there are already too many different kinds of technical degrees, and that the number should be diminished, rather than increased.

3. My own opinion as to the specific suggestion to institute this new degree, is that in order to attain the fullest professional efficiency, a man devoting himself to mining geology should first have a mining engineering training. In expressing this opinion I do not lose sight of the fact that there are a number of mining geologists of high standing who have not taken the mining degree, but where this is the case I believe that many of the most successful and efficient men have, by field study in mining regions, largely made good such technical deficiencies as they may have recognized in themselves.

On the whole, I think it would be most desirable, for a man who intends to specialize in Mining Geology, to secure first a good training in mining engineering.

ROBERT PEELE.

Sir: In response to your inquiry I may strike the keynote of my comments by remarking that at present academic degrees in this country have very little significance. Fundamentally, possession

of a degree is no proof of exceptional ability; it merely shows that its holder has spent a certain period in university or equivalent training for his life work and that he has passed certain academic tests. It could be more truly evaluated if it were the custom to write after the symbol for the degree the abbreviated name of the institution by which it was conferred, thus William Jones, Ph.D. (Harv.), the particular form of abbreviated name to be fixed by the degree-conferring body and to be virtually a part of the degree.

I am strongly of the opinion that no degree should correspond exactly in form to the plain English designation of a member of a profession. In other words, there should be a clear distinction between a formal title or degree and a common professional designation. In accordance with this view, for example, *mining engineer* is not a proper academic degree; for many men are capable mining engineers who hold other degrees or none at all, and these men have as much right to call themselves mining engineers as the purveyors of bread have to call themselves bakers. This objection would be largely obviated if the name of the university or school were always coupled with the degree. Even then, however, it would be better to make the degree distinctly different from the common appellation for the members of the profession.

The profession of medicine stands apart, since by law and long custom, only the holders of a recognized degree may practice; but even here it is to be observed that the abbreviation M.D stands properly not for "doctor of medicine" or "physician" but for *Medicinæ Doctor*. Some such differences as I have suggested should mark off the holder of a professional degree from other members of his profession if the degree is to have any significance whatever. To confer the degree of *mining geologist* with the idea of securing academic preemption of that designation would be a piece of futile scholastic arrogance.

I believe that the granting of a professional degree, in accordance with the principles that I have outlined, to indicate special

training in economic geology is desirable. The bachelor's degree should be prerequisite to its attainment.

F. L. RANSOME.

WASHINGTON, D. C.,
February 11, 1916.

Sir: Referring to the question of American universities granting a new degree to be known as that of "mining geologist," I have read with much interest the proof of Professor Haworth's article, and although I have no time to write out a finished article on the question, I am glad to give my personal opinion.

I am heartily in favor of the granting of such a degree, and believe that it should be placed on a par with the degree of mining engineer, civil engineer, or electrical engineer. In order to obtain the degree, a candidate should complete the regular course in geology calling for a bachelor's degree, and in addition, should take at least one year's post-gradute work covering practical subjects, thesis, and the relation of geology to such practical questions as the development, management, and financing of properties. The great weakness of many engineers and geologists lies in their inability to make the results of their labors practical. If a man obtained a training qualifying him to apply his theoretical knowledge in securing practical results, such a thing should be recognized. The requirements for an A.B. degree do not involve the practical application of knowledge, and I should say this new degree should mark the differences between the theoretical training and the ability to apply theoretical knowledge to practical problems.

A case coming under my observation is an interesting one. This man has three college degrees, viz.: A.B., A.M. and Ph.D., but he early recognized the fact, in going into the professional field outside of the government bureaus, that none of these degrees would add at all to his prestige with practical men. In fact he was inclined to think that a disarrangement of the alphabet after a man's name was a handicap rather than an asset to him in the busy man's world; but he felt that something should

follow a man's name to indicate his profession. At first he used the common expression "consulting geologist," which is rather indefinite. He wanted something to indicate the fact that he was a geologist and mining engineer engaged in the oil business. He could find no combination that was entirely satisfactory, but finally adopted the rather inelegant term of "geologist and petroleum engineer." The last two words do not fit together at all well, and I am inclined to believe that the words "petroleum technologist" would be much better.

His work at first consisted in developing geological problems. He was gradually called into conferences regarding development, and finally into the financial side of the oil business. I believe that the degree of "mining geologist" would have covered his activities for the first two or three years after he left the U. S. Geological Survey, but since then enough of his work has been along strictly engineering and financing lines to merit a new title. In this connection, therefore, I believe that colleges will sooner or later come to adopt a degree of "petroleum technologist," which will indicate a man's preparedness to handle those problems involved in the recovery, transportation and marketing of oil and the financial problems incident to such activities.

The University of Pittsburgh, under the able direction of Roswell H. Johnson, and Stanford University, under the equally efficient geologist and technologist, V. R. Garfias, are giving special courses aimed to prepare a man to cover the field of petroleum technology. These departments are both young. In fact, the science of petroleum geology and technology, if it may be honored with a separate name, has been developed within the past ten years, so that the granting of a degree covering such a branch of science and engineering would probably be premature at this time; but I believe that economic geologic training has reached a point where we are fully justified in granting a degree of "mining geologist," and that later on the term of "petroleum technologist" can be well applied to those men who are specializing along these ever-expanding lines of geology and engineering.

RALPH ARNOLD.

Sir: I have read with much interest Mr. Haworth's letter. The argument presented by him in favor of universities granting a special degree for proficiency in geology is interesting, but to my mind hardly conclusive. The suggestion is worthy of careful consideration and is certainly very timely owing to the increasing demand for the services of well trained and really expert economic geologists. This has resulted already in the assumption of the titles of "mining geologist," "economic geologist" or even of "practical geologist" by a number of irresponsible practitioners with hardly a smattering of knowledge of geology to back up their pretensions.

To put a check on this growing practice, and at the same time to give added dignity to those whose higher education in geology entitles them to it, Professor Haworth suggests the establishment of a degree other than those already provided for by the universities and mining colleges of this country, which would designate to the public the recipients' proficiency in geological science.

The first requisite for such a step would seem to imply the necessity for the establishment of such a uniform geological curriculum by all colleges as would insure a definite minimum of instruction to the recipient of the degree.

The title of the degree would seem to me to be very immaterial, if the fundamental quality of instruction be provided for.

Outside of the older degrees of divinity, medicine, law, and philosophy our colleges have all, of late years, so multiplied the number of subjects for which they grant diplomas and degrees, that an additional one more, offers no valid objection. On the other hand all these newer degrees are granted for concrete applications of abstract sciences and are mostly classed under the head of engineering. The geologist, however, even when working out the economic application of his investigations barely leaves the realm of abstract science, and therefore it would seem that any degree conferred for proficiency in this branch should be classed with the older rather than with the more recent ones.

The study for the degree in geological science should by all means be a post-graduate course following the regular curriculum for mining engineering, and consequently should bear with it a higher degree of honor. I should think it should be on a parity with any of the other doctorate degres, and might properly be entitled "Ph.D. in geology."

The foregoing remarks are all based on the supposition of the advisability or necessity for the establishment of such a distinctive degree in the profession. Frankly, while I see no objection to it, I think that the demand for it is overestimated, and that it would be unwise to offer this specialty of extra study as opening a new field to the young engineer, unless it was clearly explained that it must be supplemental to his first obtaining the degree of mining engineer. Looked at from the professional standpoint at large the chances for permanent employment exclusively on economic geology may be considered as very limited.

It is true, that the employment of special geologists is growing, but from the very nature of the work, there can be no assurance of its permanence after the problems at issue have once been solved. The danger I can foresee in the establishment of such a department in our college courses as separate and distinct from the regular engineering curriculum, would be in attracting a much larger number of special students, buoyed up with the idea that there would be opened up for them a career for which there was an unlimited demand, and that under this impression they would subordinate their practical engineering studies to those of the more advanced geology. Would not this result very shortly in an undue excess of supply over demand and consequent disappointment of the graduate when he was called upon to face the question of earning his living?

There can be no question as to the desirability of a post-graduate course in economic geology, and the man who equips himself by taking this course will always command better salary than the one who has not done so, but that is no reason why he ought not to be able to carry on his engineering operations when his study of the special questions involved has been completed.

Give a man his regular engineering education, and supplement it with a special course in economic geology, and whether or not you add a new title to the combination so obtained, that man will have a preference over all of his competitors who are not so well equipped.

A special post-graduate or doctor's degree will always be of advantage to him, as it is now in other branches, but it doesn't seem to me necessary to distinctly differentiate the economic geologist from his brethren of the mining profession.

E. GIBBON SPILSBURY.

Sir: I have read Mr. Haworth's letter with interest. I have noticed the growing use of the title of mining geologist, and have deprecated it because it seemed to me something unrecognized, and usually employed by people who have no degrees from any institution,—people who seem to have invented the title. I think that most of the practical miners in the West rather laugh at this title, just as they do at any man who calls himself "professor" or has this title on his card. They recognize scientific "doctors," because there have been so many of them who have not been merely theoretical but practical; such as Dr. James Douglas, for instance.

I would favor the granting of this degree in courses at schools of mines or other technical institutions, if I thought that there would be a sufficient number who would wish it. Of this those engaged in academic work will be better able to judge than I; but I should imagine that if any man expected to devote himself to a particular phase of mining, he would prefer the title of mining engineer, rather than one which would seem to limit by inference his knowledge of practical mining.

Perhaps some other title might be suggested which could be given in course or after post-graduate study, but none has yet occurred to me. Possibly the title "geologist" without any prefix would be better, especially in view of the fact that with the increasing tendency of mining men to consult geologists, and the increasing number of men of this profession who are connecting

themselves with staffs of mines, it may well come about in time that when one says "geologist," he will think rather of a man engaged in the application of geological science to mining, than of one who is purely professional—that is, engaged either in the teaching or the study of the science. Why could we not use the term "economic geologist," which would include men connected with oil or development, which are not yet recognized as mining, properly speaking?

Perhaps such an agitation of the subject as you are undertaking may itself tend to solve the difficulty, inducing the mining men to use some other title, which would in turn discourage the charlatan from using it.

A. R. LEDOUX.

Sir: After thinking over the suggestion made by Mr. Haworth I can see no reason why technical schools should not give the degree of mining geologist.

Undoubtedly a great many men who go to mining schools make a special study of geology and after a time become particularly expert in giving advice as to the persistency of ore-bodies and the best methods of exploration. They are not supposed to be able to advise as to the most proper procedure in mining or treating ore, or as to costs, but leave these points to the man who is, strictly speaking, a mining engineer.

The more knowledge and experience a mining engineer proper has along geologic lines, of course, the better man he is; but the field of mining engineering is now so wide that specialization has become a necessity, and the engineer may as reasonably specialize in geology as in mining methods or metallurgy.

Some universities give the degree of metallurgical engineer in contra-distinction to that of mining engineer, and there appears to be no valid reason why the degree of mining geologist could not be granted with equal propriety.

On the other hand there is a growing feeling at some of the large universities, notably Columbia, that the multiplicity of engineering degrees is being carried too far, and it has been

seriously proposed that at Columbia only one engineering degree be given, and that the graduate specialize during his course and after graduation.

I am not prepared to accede to this proposition though I know when we get to the point of graduating road engineers, efficiency engineers, etc., the situation is somewhat complex. It may therefore well be that the universities would object to still further adding to this complication.

From the practical point of view I do not think it is possible to prevent an unauthorized man from putting after his name, "mining geologist," any more than in past years he could be prevented from writing mining engineer or M.E. after his report, even if he had never been inside a technical school. In fact twenty years ago any man who signed a report invariably put M.E. after his name. Such men seldom wrote E.M., not knowing that Columbia, for instance, gave the degree, not of mining engineer, but of engineer of mines. If indeed during that time a man wrote E.M. I knew that he probably was a technical graduate.

This is the practical side of the case, and whether the granting by universities of the degree of mining geologist would in any way help the geologic branch of the profession, I am unable to say.

J. PARKE CHANNING.

Sir: In regard to the granting of the degree of mining geologist by universities, it is certainly true that the term is used very extensively by entirely incompetent men. The only question in my mind is whether, in view of its present use, the title should be adopted by the universities, as such action might have the effect of strengthening the hands of those using it at present, giving the impression that they had the authority to do so. In this connection I always think of the case of an acquaintance who was chief engineer of a corporation and always signed C.E. after his name. On my protesting he stated that C.E. to his mind meant chief engineer, and that he did not know any law which would

prevent his using the abbreviation if he was so disposed, and he did use it up to the time of his death.

R. V. NORRIS.

A STUDY OF SOME HEATING TESTS.

Sir: The article in your number for June, 1915 (pages 348–367), by W. A. Tarr, entitled "A Study of Some Heating Tests, and the Light They Throw on the Cause of the Disaggregation of Granite," makes very clear the fact that the inclusions in the quartz of a granite have very little to do with the shattering and weakening of the rock by heat. The principal cause of the shattering, as the author clearly points out, is the unequal expansion of the constituent minerals. I cannot agree, however, with his statement that the inversion of quartz at 575° plays no part in the disaggregation. The author seems to have misinterpreted the work of Fenner and others on the inversions of quartz, as appears from the statement (page 366): "As most granites are believed to have cooled above 575° C. and below 870° C. the first change [inversion of alpha to beta quartz at 575°] would not be effective in this study," evidently assuming that the quartz of granite is beta- or high-temperature quartz. The fact is that no high-temperature quartz has ever been found at temperatures below 575°; the inversion is strictly reversible and occurs without appreciable lag as soon as the temperature passes 575° in either direction. It therefore is bound to exercise a considerable influence in the expansion of granite. The tests themselves indicate this, for "the strength declines rapidly to about 500° or 600° C., and at 800° C. the stone is rendered worthless."

We have recently shown the effect of the 575° inversion experimentally[1] in the case of several granites. The curve of volume against temperature for granite has exactly the same shape as that for pure quartz, with the rapid rise near 575° and the sudden change of direction at that point. On cooling from about 600° and reheating, a curve parallel to the first is obtained,

[1] "The Determination of Mineral and Rock Densities at High Temperatures," *Am. Jour. Sci., 37,* 1–39 (1914). *N. Jahrb. Min.,* etc. *1915,* Beil. Bd. *40,* 119–162.

but starting from a slightly larger initial volume; the increased volume is the result of the permanent pushing apart of the minerals caused by the first expansion and inversion.

The fact that strain effects are observed in the feldspar as well as in the quartz is used as an argument against the hypothesis that the quartz has produced a large shattering effect by its inversion. It is probably true, in the case to which this is applied, that the quartz has not exerted any effect by its tendency to invert to tridymite. But the strains are to be looked for, not only in the expanding mineral itself, but in its neighboring minerals which it drags along or wedges apart. As for the different expansion coefficients of a mineral in different directions, these do not, of course, produce any strains in the mineral grain itself, except as they are differently restrained by their neighbors.

The essential cause of the shattering of granite by heat is therefore divisible into two parts: (1) the wedging and straining effect due to the fact that the minerals, originally in close contact, possess different coefficients of thermal expansion; (2) the similar effect produced by the rapid volume increase of quartz as its 575° inversion point is approached, and by the final sudden increase in volume at 575°.

ROBERT B. SOSMAN.

ORIGIN OF CERTAIN ORE-DEPOSITS.

Sir: I have read with much interest the contributions by Professor L. V. Pirsson and Mr. J. E. Spurr entitled "Origin of Certain Ore-Deposits," contained respectively in Vol. X., Nos. 2 and 5, of ECONOMIC GEOLOGY. In these papers the possibility of an igneous origin is suggested for the zinc and lead ore bodies of the Mississippi valley, and the line of reasoning adopted by Professor Pirsson in the original article is exceedingly interesting. In this connection I would like to draw attention to a group of veins occurring in Ontario and Quebec, of whose origin Professor Pirsson's suggestion may afford an explanation. In fact, the suggestion seems to be decidedly more applicable to these veins than to the deposits of the Mississippi valley.

There are a great many individual deposits in the group, and

the majority of them are strikingly similar in structure and composition. There is an intermediate type and two end types. The chief characteristics of the veins are given below:

1. The veins occur in Ontario and Quebec, traversing areas of Pre-Cambrian, Cambrian and early Ordovician rocks. Their strike, with rare exceptions, is northwesterly.

2. The chief deposits of the group are:[1]

(*a*) Frontenac lead vein, Frontenac County, Ontario.
(*b*) Kingdom lead vein, Fitzroy County, Ontario.
(*c*) Hollandia lead vein, Hastings County, Ontario.
(*d*) Katherine lead vein, Hastings County, Ontario.
(*e*) Ramsay lead veins, Lanark County, Ontario.
(*f*) Bedford lead veins, Frontenac County, Ontario.
(*g*) Lansdowne lead veins, Leeds County, Ontario.
(*h*) Union Creek lead vein, Peterboro County, Ontario.
(*i*) Hull and Buckingham lead veins, Ottawa County, Quebec.
(*j*) Indian Cove lead veins, Gaspé, Quebec.
(*k*) Fluorite veins, near Madoc, Ontario.
(*l*) Rossie lead vein, St. Lawrence County, New York.

3. The deposits are fillings of fissures, and are not replacements. Usually they are bounded by smooth slickensided walls. In a few instances these fissures are recognized to be fault fissures, on account of the juxtaposition of rocks of different ages in the walls. In other cases there is considerable evidence of brecciation, which suggests differential displacement of the walls. All of the veins that have been examined by the writer are of the pinch-and-swell type, and it is quite likely that the remaining ones show the same characteristics. Fractures of such a character are usually found in fault zones.

4. The chief vein-filling minerals are calcite and barite. Calcite is the predominant gangue in the wider veins, as at the Frontenac, Hollandia and Kingdom properties, while barite is more abundant in the narrower veins.

[1] Descriptions of these and other properties will be found in Part 2, 25th Annual Report, Bureau of Mines, Toronto, Canada, 1916.

5. Fluorite is found occasionally as a gangue mineral. It has been reported as occurring in the calcite-galena veins of Hull county and Gaspé, Quebec, and in the veins at Rossie, New York state. In eastern Ontario, near Madoc, are two veins, to all appearance belonging to the same series, which consist predominantly of massive fluorite, and one of these veins cuts early Ordovician limestone.

6. The chief ore mineral is galena. It usually occurs more or less richly disseminated in grains and clusters throughout the gangue. Sphalerite frequently occurs in small amount. It is similar in appearance to that of the upper Mississippi valley district. Accessory minerals consist of pyrite, marcasite, chalcopyrite and quartz.

7. As a general rule the ore minerals may be described as non-argentiferous. In some places, however, they contain as much as one ounce of silver to the ton of galena. This proportion is not far different from that in the Mississippi Valley deposits.

8. The veins are of the crustified type, and in places this banding is accentuated by the presence of the ore minerals between successive bands of the gangue. The individual bands break very readily from each other.

9. The intermediate or most common type of vein in this group is one consisting of calcite and barite in about equal proportions, with from 4 to 15 per cent. of metallic sulphides. One of the end types consist of veins with calcite alone as a gangue, while at the other extreme are the fluorite veins. Every gradation exists within the series.

10. In the Gaspé Peninsula of eastern Quebec, dikes of greenstone are found cutting the limestones of the Ordovician in which the mineral deposits occur. In southern Quebec and New England the rocks of the Ordovician are intruded and intensely deformed by the disturbances of the Taconic Revolution. In eastern Ontario, where the fluorite veins are found, there are no known post-Ordovician intrusives closer than 175 miles. It is interesting to note, however, that intrusives are found on the outskirts of the district in which the veins occur.

11. The vein at the Kingdom Lead Mine is a filling of a well-marked fault fissure, which is one of a series of northwest striking faults which are abundant in the neighborhood of the city of Ottawa.[2] It is possible that other fractures of this fault series may be mineralized with calcite, galena, etc. It is also possible that similar calcite-barite-galena veins occurring in other parts of the district may be fillings of fault fissures of the same series, although the evidence of differential movement may not be as clear as at the Kingdom mine.

12. It has been estimated by E. M. Kindle and L. D. Burling[3] that some of the faults have a differential vertical displacement of 1,800 to 2,000 feet. This would indicate that the fractures probably extend to great depths.

13. The location of several of the deposits with respect to others suggests that the zones of dislocation extend for long distances in a northwesterly direction across eastern Ontario. It seems probable for instance that the Rossie, Lansdowne and Bedford groups of veins are all located at different points along the same dislocation zone. This evidence regarding the extension of the fissure systems along the strike, therefore, is in accordance with the evidence concerning the extension of the fissures to considerable depth.

A detailed study of any one or two of the largest deposits, the Frontenac Lead Mine for example, would in all probability lead to the conclusion that the vein materials were deposited from circulating meteoric waters. There are no minerals or substances in the veins that might not readily have been derived from the surrounding limestones of the region. The gangue of the vein is almost entirely calcite. Galena, sphalerite and pyrite exist in small amounts in most limestone formations, so that the natural conclusions as to the origin of the deposits would be that they were concentrations of materials derived from the surrounding and previously eroded portions of the country rocks. In appear-

[2] Geol. Surv. of Canada, Museum Bull. No. 18, 1915, by E. M. Kindle and L. D. Burling.

[3] *Idem.*

ance, most of the veins resemble closely some of the vein deposits of the Mississippi valley region, which are generally supposed to be of meteoric origin.

The suggestion recently made by Professor Pirsson with regard to the possibility of an igneous origin for the zinc and lead deposits of the Mississippi valley region is in harmony with the hypothesis suggested in this paper for the genesis of the Ontario-Quebec veins. The features which suggest that the Ontario-Quebec veins have at least a remote connection with igneous action are the following:

1. The presence of fluorite and some quartz in greater or less abundance as gangue minerals.

2. The presence of basic igneous dikes in association with some of the veins in eastern Quebec.

3. The fact that some members of vein series are known to traverse the Ordovician, which in southern Quebec was profoundly deformed and intruded during the Taconic revolution.

4. The occurrence of the veins as fillings of fault fissures, some of which show a differential vertical displacement of at least 2,000 feet, and extend over a mile along the strike.

The suggestion offered by Professor Pirsson is contained in the following extract from his paper:

> "As it is natural to believe that magma, perhaps in the pseudo-rigid but potentially liquid form conceived by Iddings, must everywhere underlie the outer rock zone, so everywhere there will be a tendency for it to rise upward when opportunity permits. One of the first effects of relief of pressure on its upper surfaces would be the liberation of the volatile constituents. It may well be that in many places no further action than this happens. All the shiftings and movements of the lithosphere would then tend in variable degree to be attended by upward movement of gaseous constituents."

In this eastern Canada district some of the fault fissures with which the vein system is associated extend to considerable depths, and it is probable that the readjustments of the earth mass which accompanied and caused their formation were of such a magnitude as to permit of the escape of volatile constituents through these fault fissures from the underlying magma. The presence of flu-

orite, sometimes in large quantities in these veins, suggests that fluorine might have been one of the volatile constituents that made its way upward at the time of the readjustment. It is difficult otherwise to explain the occurrence of the fluorite veins in eastern Ontario cutting the Ordovician in a district where the nearest post-Ordovician intrusives are distant about 175 miles. In the outlying parts of the general district in which this group is found, intrusive rocks are abundant, and they cut rocks of the same age as those traversed by certain members of the vein system. It is suggested, therefore, that the fluorite which occurs abundantly in veins cutting the Ordovician in eastern Ontario, and frequently as a minor gangue mineral in the calcite-barite veins of Quebec, has obtained its fluorine from the volatile emissions of underlying magmas. In southern Quebec these magmas are represented by igneous rocks now exposed at the surface, and the possible genetic connection between them and the veins seems quite reasonable. In eastern Ontario, however, erosion has not been deep enough to bring the same series of intrusives to the surface. Fractures accompanying the intrusion reached the surface and are now seen as mineralized or unmineralized fissures. It is presumed that these fissures were deep enough to allow the escape of certain volatile constituents of the cooling magmas, which thereby found their way to the ground-water circulation.

The suggestion is offered, therefore, that both meteoric waters and igneous emanations have played a part in the formation of the calcite-barite-fluorite-galena veins. It seems probable that the lead and zinc minerals and the calcite and barite may have been derived from the surrounding rocks by meteoric waters, but that the fluorine of the fluorite was derived from magmatic constituents which rose toward the surface through fissures produced during the post-Ordovician period of readjustment.

W. L. Uglow.

EDITORIAL

With the current issue ECONOMIC GEOLOGY begins the second decade of its literary life. With this new period a change has been made in the title page so that the purely economic aim of this journal may be more strongly emphasized in title as well as in fact. It seems appropriate that a more than passing mention of the *American Geologist,* and of its able and faithful editor should accompany this change.

The long record for useful, and for years, pioneer service, of the *American Geologist* whose now final passing comes so soon after the death of N. H. Winchell, merits a larger share of notice and a deeper appreciation than those which find expression in a brief "in memoriam" of its editor.

In these days when science moves so rapidly, forgetfulness comes quickly, and the infinite patience and labor which are the cost of first steps become so soon dimmed by time, that in the light of later facilities for progress they often seem inappreciable. The papers by Bain and Upham which appear elsewhere in this issue will give some idea of the magnitude of the work of Winchell and his colleagues for geology, and may in some measure serve as a tribute to his industry and patience.

Readers will recall that shortly after the first issue of the journal in 1906 a consolidation was effected with the *American Geologist* which, for nearly twenty years under the able editorship of N. H. Winchell, had performed a notable service to the science of geology.

The benefits of the consolidation were mutual. Winchell had felt the editorship, especially with the competition with the *Journal of Geology,* to be an increasingly heavy burden in his later years and an undue tax on his strength. That the opportunity then offered of allowing a young and vigorous journal to carry the old name and at the same time render the new publication a service seemed fortunate. ECONOMIC GEOLOGY, on the other hand, by the generous terms of the gift was enabled to secure at the outset of its career wide distribution among a large circle of readers whom it might not otherwise have been able to reach for a very long time.

During the period of years for which it was agreed that the consolidated title should be carried, and which has now expired, the editors feel that ECONOMIC GEOLOGY has filled a needed place in geologic literature, and although they are fully conscious of the many avenues along which improvement should be sought, that it has gained a recognized place among geologic publications. Because the function, however, which it was especially designed to perform is so exclusively economic, and because topics of purely general geologic interest are many of them so little germane to the field of applied geology, the fitness of laying a greater stress on the economic aim seems manifest. For these reasons we wish to signalize the beginning of the second decade of the journal's literary life not only by an urgent request for the continued support and interest of our subscribers, but by these few words of appreciation of the work of the *American Geologist,* the first important step in American geological journalism.

REVIEWS

Wabana Iron Ore of Newfoundland. By ALBERT ORION HAYES, Can. Dept. of Mines. Geol. Survey Mem. 78, No. 66, Geol. Ser., 1915.

This report is the first one of importance which has appeared describing in detail the structure, texture, and origin of the Newfoundland iron ores, and is a distinct contribution to the geology of sedimentary iron ore deposits. The first part of the paper gives the general distribution, stratigraphy, paleontology, petrology and chemistry of the ores and associated rocks, while the last part deals with the origin of the ores. There are a large number of excellent microphotographs of the ore.

The Wabana iron ores occur in rocks which belong to the lower Ordivician, ranging in age from Arenig to Llandeilo of the British Isles, which is equivalent to the Beekmantown, Chazy and Black River formations of the northern Appalachian region. The iron ore district is in the extreme eastern part of Newfoundland, the present working mines being situated on Bell Island in Conception Bay and in submarine areas to the northwest.

The eastern portion of Newfoundland consists largely of pre-Cambrian crystalline rocks but along the shores of Conception Bay and on islands in the bay sedimentary rocks ranging in age from lower Cambrian to lower Ordovician are found outcropping. This series of rocks, consisting principally of interbedded, well-indurated sandstones, shales and slates, reaches a thickness of several thousand feet. It is in the upper 1,000 feet of the series that the iron-ore deposits occur. The general character of the beds, such as the alternation of sandstone and shale, the lenticular character of individual layers, and the presence of ripple marks and cross-bedding, indicates that the sedimentation took place in moderately shallow water not far from the shore. The strata have a general monoclinal dip of from 8° to 10° north-northwest. (Due to a misprint on page 9 in the report the dip is given as north-northeast.)

There are many individual beds of iron ore in Bell Island ranging in thickness from only a fraction of an inch to 30 feet or more. The various layers have been grouped by the author into six zones numbered from 0 to 5, beginning with the lowest. Of the six zones, three are said to be workable, namely, Zones 2, 4, and 5, located in the upper 400 feet of strata. Zones 2 (including the Dominion bed) and 4 (including the Scotia bed)

are being extensively mined at the present time. All the ore beds except those of Zone 3 consist of oölitic hematite and chamosite with some dense compact hematite. The beds of Zone 3 consist of oölitic pyrite.

Zone 0 outcrops in the extreme southwestern part of the island and consists of a thin ferruginous band.

Zone 1 extends in a northeast-southwest direction across the island somewhat southeast of the center. It contains several bands of oölitic hematite, one or two of them reaching a thickness of two feet.

Zone 2, about 600 feet above Zone 1, outcrops in the northwestern part of the island and includes the Dominion bed extensively mined by the Dominion Iron and Steel Company. The Dominion bed is said to have an average thickness of ten feet and forms the uppermost ore bed of this zone. It is mostly oölitic hematite with some chamosite in the upper part. Below it, through a thickness of 100 feet, are numerous other beds of mixed oölitic hematite and chamosite, interlayered with sandstone and shale. Submarine workings on the Dominion bed extend 1½ miles north of the island.

Zone 3 occurs just above and outcrops northwest of Zone 2. One to three layers of oölitic pyrite occur in this zone, ranging in thickness from a few inches to a foot or more and occurring through a thickness of shale strata varying up to ten feet.

Zone 4 occurring about 210 feet above Zone 3 consists of a number of layers of mixed oölitic hematite and chamosite interbedded with sandstone and shale, the entire zone being included along the outcrop in a thickness of about fifteen feet. The principal bed is the Scotia bed usually averaging about eight feet in thickness but ranging up to 30 feet in thickness in the submarine area, and extensively mined by the Nova Scotia Steel and Coal Company both along the outcrop and in submarine areas. The beds consist principally of oölitic hematite with intermixed chamosite. A persistent thin layer of chamosite occurs at the top of the Scotia bed.

Zone 5 outcrops along the northwest shore of the island. Beds of oölitic hematite occur at intervals through fifty feet of strata, the zone as a whole being separated from Zone 4 by forty feet of sandstone and shale. The lowest of the hematite bands in Zone 5 is known as the Upper ore bed and reaches a thickness of five or six feet.

The ore beds vary in thickness from place to place, although the ore zones as a whole are very continuous. They show ripple-marked surfaces and some show cross-bedding. Fossils are abundant, especially brachiopods, boring algæ and worm burrows. Graptolites occur in the oölitic pyrite and accompanying shales.

The principal ore mineral is hematite with which chamosite is abundantly associated. Siderite is important locally. Quartz occurs as

detrital fragments and in the recrystallized form. Fossil fragments of shells and tubes of boring algæ occur throughout the ore. The former consist of calcium phosphate.

The great mass of the ore has an oölitic texture, being composed of fine spherules of mixed hematite and chamosite generally somewhat flattened in direction at right angles to the bedding. This flattening is more pronounced in the middle of the beds than at the top or bottom, since in these places the spherules are generally embedded in a matrix of granular material. Elongated spheroidal nodules of dark green material varying in size up to a centimeter in diameter occur in the ore bands, either irregularly scattered or arranged parallel to bedding planes.

The rocks associated with the ore beds are fine-grained ferruginous sandstones and shales of greenish gray to grayish black color. The ore beds themselves are reddish brown in color, the leaner portions having a greenish tinge due to a more abundant admixture of chamosite. Chamosite also is abundant in the associated sandstones and shales.

The spherules which make up so large a part of the ore are composed mainly of hematite and chamosite arranged in concentric layers about a center. Some spherules consist almost entirely of hematite while others have a distinct central portion of nucleus, which may consist of detrital quartz, of a shell fragment, of chamosite, or occasionally of siderite. Around this nucleus are arranged concentric alternating bands of hematite and chamosite. Even where spherules are apparently composed entirely of hematite, treatment with hydrochloric acid leaves a residue of gelatinous silica showing the presence of the silicate. In general the matrix between the spherules consists of chamosite but locally hematite, quartz or siderite may be associated with chamosite, or may altogether replace it. While the chamosite in the spherules is amorphous, that in the matrix is generally finely crystalline. Locally larger tabular crystals occur. In the leaner portions of the ore beds spherules consisting entirely of chamosite are abundant.

The abundant presence of the green aluminous ferrous silicate chamosite both in the ore and in the associated rocks is of great interest because of the similarity of its occurrence and texture to that of the green ferrous silicate greenalite in the iron formation of the Mesabi district of Minnesota, and the green silicate locally found in beds of Clinton iron ore in the Appalachian region. I have had an opportunity to examine thin sections of Wabana ore and was struck by the extreme similarity in appearance between the leaner portions of this ore and the greenalite rock of the Mesabi district. In the greenalite rock, however, the matrix between the greenalite granules consists either of chert or of radiating crystals of an iron amphibole (grünerite?). Chert locally replaces part of the greenalite granules and siderite may occur both in the granules

and in the matrix. The greenalite granules themselves are amorphous, are olive green in color, and do not show the concentric layering characteristic of the chamosite spherules of Wabana ore and the oölites of Clinton ore. In a thin section their shape is circular, oval, or elliptical.

The green silicate in the oölitic Clinton ores, which is believed by McCallie to be glauconite, occurs in the center of many of the hematite spherules. It forms a granular green or yellowish green nucleus surrounded by secondary silica which in turn is surrounded by hematite or by alternate layers of hematite and silica. The ordinary spherules in the Clinton oölitic ore consist of a nucleus of quartz or shell fragment around which are alternate concentric layers of hematite and silica or of hematite and calcite, the matrix between the spherules being mainly calcite and detrital quartz. It is believed by McCallie that the green silicate glauconite is the original mineral from which Clinton ores were derived, just as the greenalite rock is the original rock from which the Mesabi ores were derived.

In connection with the chemistry of the ores an interesting point brought out is that the phosphorus content of the ores is derived almost entirely from calcium phosphate composing the shell fragments and that calcium carbonate is of very subordinate importance both in the ores and associated rocks.

The author gives the range in mineral composition of the ores as follows:

	Per Cent.
Hematite	50–70
Chamosite	15–25
Siderite	0–50
Calcium phosphate	4– 5
Calcite	0– 1
Quartz	0–10

The discussion of the origin of the ores like most similar discussions made in the past is unsatisfactory. However, a number of interesting points are brought out.

The author gives as his belief that the ores are primary bedded deposits originally laid down, together with the enclosing rocks, in much the same form as they occur now. The hematite and chamosite are supposed to have been deposited together, more or less at the same time, though perhaps under slightly different conditions. The spherules are believed to have been formed under the action of surface tension by the accumulation of extremely fine-grained unconsolidated ferruginous sediments. That the deposits are of marine origin is indicated by the fossils and that they were laid down in shallow water is shown by the presence

of ripple marks and cross-bedding. However, but little detrital material accompanied their deposition.

The author makes a strong point of the presence of tubes of boring algæ which penetrate both the spherules and the matrix showing that both were essentially in their present form before consolidation took place. The spherules were probably flattened while in a soft condition due to the weight of overlying material. However, not only do the boring algæ penetrate hematite and chamosite, but they are present even in the siderite which in general is supposed to be secondary to the other minerals.

These algæ are believed by the author to be at least in part responsible for the deposition of the iron compounds. From the description it may be presumed that the author believes these algæ to be the same as the organisms now known as "iron bacteria" including *Gallionella, Leptothrix* and others, and Beck is given as the authority for the statement that these bacteria are abundant on the sea bottom. The author then proceeds to explain how these organisms being present in ferrous sediments would by their life processes give off oxygen which would oxidize the ferrous compounds along the walls of the tubes, and thus produce the lining of hematite occurring along these tubes. He states further that these algæ probably belong to the Cyanophyceæ or blue green algæ and believes that they may be in large part responsible for the hematite which occurs in the ores even other than that which lines the algæ tubules.

In general he sees the process of deposition as follows: Iron salts brought to the sea sink to the bottom on account of their higher specific gravity and are acted upon by ammonia formed by the decomposition of organic matter and are precipitated as iron hydroxide (whether the author means ferrous or ferric hydroxide is not stated). The oxidizing action of the algæ is then supposed to have oxidized part of the iron hydroxide to hematite while various silicates of alumina present in the ooze combined with other portions of it to form chamosite and other iron silicates. This combination of materials has then by physical processes been segregated into little concretions or oölites which gradually hardened and locally were partly replaced by siderite.

There are various discrepancies in this discussion which should be pointed out.

In the first place the iron bacteria to which the formation of these ores is at least in part attributed have never been known to occur in the sea, although it is possible that at some future time they may be found to exist there. Secondly, the activities which are ascribed to the iron bacteria, *i. e.*, the oxidation due to giving off of oxygen does not necessarily require the presence of these organisms. Most species of plants

give off oxygen in their life processes and therefore ordinary algæ would effect the same result as is here ascribed to the special group of iron bacteria.

The question as to whether ferric hydroxide or any other iron compound except iron sulphide can be precipitated in the presence of abundant decaying organic matter seems to me to be a very doubtful one. It would seem that, under these conditions, the ammonia would probably change immediately to form ammonium carbonate and be inert. Besides, the abundance of carbon dioxide present in the water under these conditions would tend to keep the iron in solution. It may be suggested that perhaps iron bacteria were an important agency in taking the iron out of solution.

The formation of the oölitic pyrite beds, which have been mentioned as occurring just above Zone 2, is believed to have resulted from a deepening of the waters. Their probable equivalents are found today in the black and blue muds rich in iron sulphide occurring in the Black Sea and other localities.

E. C. HARDER.

SCIENTIFIC NOTES AND NEWS[1]

V. H. HUGHES has recently returned from Tampico, Mexico, where he spent two months in geological work connected with petroleum.

THE ASSOCIATED GEOLOGICAL ENGINEERS have opened a New York office at 120 Broadway. F. G. Clapp is managing geologist of the petroleum division.

DR. WILLIS T. LEE, of the United States Geological Survey, spoke before the Section of Geology and Mineralogy of the New York Academy of Sciences on March 20 on the "Application of Physiographic Methods to the Correlation of Non-marine Formations in the Rocky Mountains."

WILLET G. MILLER, provincial geologist of Ontario, sailed on the "Adriatic" in February. He will be at the Ontario Government Office, 163 Strand, W. C.

MR. ELLIOT BLACKWELDER, professor of historical geology at the University of Wisconsin, has been appointed professor of geology and head of the department, at the University of Illinois. The new arrangement will take effect September 1.

THE WEST VIRGINIA GEOLOGICAL SURVEY has just issued a "Detailed Report on Lewis and Gilmer Counties," by D. B. Reber. A separate case of topographic and geologic maps accompanies the report.

DR. FRANK A. HERALD has recently returned to America from China, where he has been making geological investigations of the possibilities of oil and gas fields for the Standard Oil Company of New York. At the present time he is engaged in oil and gas work with field headquarters at Pawhuska, Okla.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

PROFESSOR L. V. PIRSSON, of the Geological Department of the Sheffield Scientific School of Yale University, is recovering from an attack of rheumatism at Hot Springs, Arkansas.

READERS WILL BE GLAD to learn that Professor J. F. Kemp, of Columbia University, who has been suffering from a severe illness, is much improved. During his absence the work of the geological department has been under the charge of Professor Charles P. Berkey. A portion of the work has been divided between Professors Heinrich Ries, of Cornell, Joseph Barrell and J. D. Irving, of Yale, Waldemar Lindgren, of the Massachusetts Institute of Technology and George P. Merrill of the National Museum.